PROCEEDINGS
THE INSTITUTION OF CIVIL ENGINEERS

PART I
NOVEMBER 1955

ORDINARY MEETING

26 April, 1955

WILLIAM KELLY WALLACE, C.B.E., Vice-President, in the Chair

It was resolved that Messrs H. M. Bostandji, H. R. Boyce, D. A. Brown, Robert Carey, E. W. Cuthbert, R. W. A. Fane, E. C. Lightbody, and H. Ridehalgh, be appointed to act as Scrutineers, in accordance with the By-laws, of the Ballot for the election of the Council for the year 1955–1956.

The Council reported that they had recently transferred to the class of

Members

Adlington, Bertram George Fletcher, B.Eng. (*Sheffield*).
Alley, George Dermot Shillington, B.E. (*National*).
Beckett, Allan Harry, B.Sc.(Eng.) (*London*).
Boddington, Thomas James, B.Sc. (Eng.) (*London*).
Bridges, George Percival.
Caldicott, Geoffrey Harvey, B.Sc. (*Edinburgh*).
Cornish, Vernon Francis, B.Sc.(Eng.) (*London*).
Ferguson, William Russel Walton, B.Eng. (*Sheffield*).
Fitzgerald, Robert Desmond.
Gardner, Stephen Verrall.
Graham, John Glover, B.Sc. (*Glasgow*).
Hodgson, John Wright.
Hunter-Brown, *Colonel* Geoffrey Howard, B.A. (*Cantab.*).
Nest, Guy.
Shepley, Eric, B.Sc. (*Manchester*).
Stewart, Donald Arnott, M.B.E.
Williams, Leonard Walter, B.Sc. (Eng.) (*London*).
Young, John McHardy, B.Sc. (*Glasgow*).

and had admitted as

Graduates

Ainsworth, James Rex, B.A. (*Oxon.*).
Ambrose, Roydon John, B.Sc. (*Wales*).
Ashford, Robert Eric, B.Sc.(Eng.) (*London*).
Barnard, Raymond Frederick, Stud. I.C.E.
Barry, Peter Raymond, Stud.I.C.E.
Berry, Frank, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
Budleigh, John Kenneth, Stud.I.C.E.
Bury, Ronald Mark, B.Sc.Tech. (*Manchester*), Stud.I.C.E.

Butcher, William Raymond Vance, B.Sc.(Eng.) (*London*).
Campbell, Robert, Stud.I.C.E.
Chia, Harold Albert, B.E. (*Western Australia*).
Colbert, Lawrence Allan, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Collins, David Thomas, B.Sc. (*Edinburgh*), Stud.I.C.E.
Davis, Reginald Maurice, B.E. (*New Zealand*), Stud.I.C.E.
Duckworth, Frederick Warren.
Dyton, Francis John, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Fitzgibbon, John Pearse, B.E. (*National*).
Fitzpatrick, Patrick Alan, B.Sc.(Eng.) (*London*).
Flaxman, Edward Wasley, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Fowles, Eric, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
Fribbance, William Lawrence.
Gibson, Geoffrey Peter, B.Eng. (*Liverpool*).
Glick, David Harvey, B.Sc. (*Leeds*), Stud.I.C.E.
Glick, Graham Lionel, B.E. (*Western Australia*).
Goldsbro', Peter George, Stud.I.C.E.
Green, Geoffrey Thomas, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
Griffin, Bryan Edward, Stud. I.C.E.
Gubbay, Lucien, B.A. (*Oxon.*).
Hall, Stanley Frederick, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
Herries, Victor Noel.
Hutton, John Robert, B.Sc. (*Witwatersrand*).
James, Glyn Evans, B.A. (*Oxon*).
James, John Arthur.
Jones, Neville Hewitt, Stud.I.C.E.
Jones, Owen Trevor, B.E. (*New Zealand*).
Jordan, Gerald William, B.Eng. (*Liverpool*).
Kilpatrick, Hugh James, B.Sc. (*Edinburgh*), Stud.I.C.E.
Lang, Lewis John.
Lapes, Peter, B.Eng. (*Sheffield*).
Leck, George Yuill, B.Sc. (*Glasgow*).
Leslie, David Duncan, B.Sc.Tech. (*Manchester*).
Levelt, Henricus Longinus Antonius Maria, B.Sc. (*Cape Town*).
Lewis, Brian John, M.S. (*California*), B.Sc. (*Durham*), Stud.I.C.E.
Lewis, John Reginald Jones, B.Eng. (*Liverpool*), Stud.I.C.E.
Lindsell, Harry John Count, B.Sc. (*Witwatersrand*).
Love, William Fairley Morton (*Jun.*), Stud.I.C.E.
Lowth, Gerald Simon, B.A. (*Cantab.*), Stud.I.C.E.
Luxton, Trevor Francis, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Lynch, Patrick Joseph, Stud.I.C.E.
McKain, William Thomas, B.Sc. (*Aberdeen*).
Manning, Ian Robin Gideon, B.A. (*Cantab.*).
Mendoza, Alex Francis Mark, B.Sc. (Eng.)(*London*), Stud.I.C.E.
Millar, Robert Fraser, B.Sc. (*Glasgow*), Stud.I.C.E.
Morrison, Gordon Kennedy, B.Sc. (*Durham*).
Nash, Anthony William, B.E. (*National*).
Paterson, John Murdoch, B.A., B.A.I. (*Dublin*).
Phillips, Alan, B.Sc.(Eng.) (*London*).
Robertson, Robert Bell, B.Sc. (*St. Andrews*).
Rowe, William, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
Rowsell, Kenneth.
Sandell, Cedric, B.Eng. (*Sheffield*), Stud.I.C.E.
Schep, Johannes Jacobus Gerardus, B.Sc. (*Cape Town*).
Schokman, Gerard Semonne Malcolm, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Scriven, William Edward, B.Sc. (Eng.) (*London*).
Simpson, John Brown, B.Sc. (*Glasgow*), Stud.I.C.E.
Sinclair, Brian Mowlem, Stud.I.C.E.
Singh, Amer, Stud.I.C.E.
Slabber, Cornelis Adriaan.
Slaughter, Colin Duncan, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Smith, Bryce Hubert, Stud.I.C.E.
Spink, John Lewis, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Staynes, Barry Wootton, Stud.I.C.E.
Sullivan, John Howard, B.Sc. (*Bristol*).
Taberner, John Pinder, B.A. (*Cantab.*), Stud.I.C.E.
Verge, Geoffrey Charles, B.C.E. (*Melbourne*).
Watkinson, Graham, B.Sc. (*Manchester*), Stud.I.C.E.
Wellington, Sydney Peter Gillies, Stud.I.C.E.
Wignaraja, Sathiavan, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Williams, Alan, B.Sc. (*Leeds*), Stud. I.C.E.
Williams, Terence John, B.Eng. (*Sheffield*).
Woodcock, John Peter.

and had admitted as

Students

AINSWORTH, DAVID WINDER ROSTRON.
BAILEY, BRIAN ARTHUR.
BAKER, RODNEY ALEC.
BARKER, GEOFFREY CLAYTON.
BASSETT, JONATHAN WILLIAM.
BROOK, KENNETH MICHAEL.
BROWN, CHARLES WALTER.
BROWN, MERFYN NICHOLSON.
BROWN, THOMAS CAMERON.
CAULFIELD, PATRICK JOHN.
CHESSMAN, GEORGE RICHARD.
COLEMAN, DERRICK ALFRED.
COX, ANTHONY THOMAS.
COX, PETER NORMAN.
CRANSTON, WILLIAM BALLANTYNE.
CUSS, DAVID GEORGE.
DANBURY, MICHAEL FRASER.
DARLING, CHRISTOPHER JOHN.
DEAN, JOHN.
DOWNES, JOHN RICHARD JULIAN.
DUTCH, WILLIAM GRANT.
EDDLESTON, JOHN DAVID RITZEMA.
EGWUATU, GORDON CHUKWUKA.
ELLIS, DAVID BRIAN.
EL-MOOSA, FALEH MAHMOOD
EVISON, JOHN
FARMER, PETER MICHAEL.
FISHER, JOHN.
FORD, ALAN KEITH.
FRASER, IAN MACLEAN.
GARI, ADAMU SABON.
GHOSH, SUIL KUMAR.
HARRIS, GEORGE BENJAMIN.
HILL, BRIAN THOMAS.
HILL, DAVID HENRY.
HOOD, CHARLES ELLIOTT.
HYETT, DAVID OSBORNE.
IRELAND, MICHAEL WILLIAM.
JEPSON, STUART DUNCAN.
JOHNSON, FREDERICK DUNCAN JOHN.
JORDAN, BRIAN WILLIAM.
KEARSEY, JOHN RICHARD MORGAN.
KIDANU, BERHANU.
KNIGHT, DEREK JOHN.
LACY, PETER ALAN.
LANGFORD, ANTHONY DAVID.
LAWN, GEOFFREY DAVID.
LOOSLEY, ALAN GEORGE.
MACARTHUR, ROBIN NISBET.
MCCALL, WILLIAM ARTHUR.
MACKNIGHT, ALEXANDER.
MCLACHLAN, COLIN.
MCNAMARA, RONALD VINCENT.
MCVIE, ALEXANDER.
MEREDITH, DAVID CECIL JOHN HANNAY.
MERRICK, THOMAS BARRINGTON.
PERKINS, JOHN REGINALD.
POOLEY, DAVID GEEN.
PRYOR, ALAN.
RIGBY, CHARLES TERENCE WILKINSON.
ROBINSON, JOHN SCOTT.
ROBINSON, MICHAEL ERNEST.
ROSE, REGINALD ARTHUR.
RYDER, RICHARD ALAN.
SAUNDERS, JOHN FRANCIS.
SIMONDS, BRIAN.
SIU-PONG CHAN.
SOMES, NORMAN FREDERICK.
SPENCE, MICHAEL.
STIEFEL, JOHN EMIL.
STURGEON, ADRIEN JOHN GORDON.
THOMPSON, BASIL CLAUDE.
TURNER, JOHN MICHAEL.
VAN DER HEEVER, JOHANNES.
WARDLE, HAROLD USHERWOOD.
WARREN, SIDNEY.
WILFORD, CHRISTOPHER LESLIE.

The following Paper was presented for discussion and, on the motion of the Chairman, the thanks of the Institution were accorded to the Author.

Paper No. 6064

POTENTIALITIES OF THE BRITISH RAILWAYS' SYSTEM AS A RESERVED ROADWAY SYSTEM

by

*** Brigadier Thomas Ifan Lloyd, D.S.O., M.C.**

SYNOPSIS

The roadways that would be obtained by converting the railways are first examined under headings: Riding Quality, Gradients, Alignment, Width, Intersections. Grounds are revealed for the belief that the resulting roadway system would be greatly superior to any existing road system.

The traffic-carrying capacity of the converted system is then considered, and, by means of a peak-load example, this capacity is shown to be appreciably greater than any foreseeable demand upon it.

There follows an outline of certain of the freight and passenger services that might be operated, bringing out their convenience and overall speediness. The feasibility of conjoining toll traffic with these services is discussed.

The broad economics of the system are considered next—a more detailed examination of the financial side of vehicle operation being given in an Appendix. The conclusion is reached that passenger fares might be as low as ½*d* per mile, and bulk freight charges 1½*d* per ton-mile. The greater but indirect benefit arising out of the efficiency of the possible transport services, as distinct from the direct saving in transport costs, is remarked upon.

Finally the Author comments briefly on certain miscellaneous aspects of the matter—including Manpower, Safety, Engineering, and Strategy—adducing further reasons for regarding railway conversion as a promising means of dealing with national transport problems.

Introduction

The adoption of the term " permanent way " was a truly inspired piece of authorship. It focused attention on the everlasting nature of what it defined—the way, the right-of-way. It placed no reservation on the means of transport and such omission can be looked upon as adjuring future engineers to use the transport methods and vehicles of their eras.

In this Paper, the Author visualizes British Railways' superb heritage of permanent ways converted into roadways reserved for fast free-running pneumatic-tired vehicles. He makes no proposals regarding the methods or the financing of conversion since their relevance as a topic for discussion is plainly a matter for individual judgement.

The resulting 20,000-mile transport system, with road vehicles using former railway routes, would bring the two forms of transportation into an amalgam preserving the mercurial qualities of road transport. The other

* The Author is Deputy Engineer-in-Chief, War Office, London.

amalgam, in which captive vehicles such as trams use roads, has been given fair trial. The Author's proposal appears never until now to have received fair professional consideration. His aim is to describe certain of its potentialities, starting with an analysis of the characteristics of the completed roadways.

Characteristics of roadways formed out of railways

Riding quality

Such comfort as is associated with railway travel must be attributed primarily to the permanent way, which runs straight and true. The intrinsic steadiness of the vehicle is severely limited by a cross-section comprising a 9-ft-wide carriage perched high above wheels that are only 4 ft $8\frac{1}{2}$ in. apart.

After conversion the way will remain straight and true; the vehicles using it will therefore inherit the primary stability of a train. In contrast with a train, however, the modern 8-ft-wide bus or lorry has approximately a 7-ft track, and the bodywork can be slung low, between the wheels rather than over them. The merits of the 7-ft axle have been argued before.

The quality of the movement will gain also from pneumatic tires; and there will be further benefit in the lessening of noise.

There remains the question of whether or not a roadway surface can equal the evenness of rails. Road engineering has been progressing strenuously towards this. An indication of what is already attainable is provided by the Motor Industry Research Association's high-speed track[1] at Lindley where, under difficult working conditions, the specified $\frac{1}{8}$-in. tolerance under a 10-ft straight-edge was often bettered. An irregularity index as low as 35 in/mile was achieved on the transverse steeply banked concrete bays; it should be noted that an index of 60 in/mile is rated as good riding quality on trunk roads,[2] and some say[3] (though others dispute it[1]) that concrete is not the easiest material to lay evenly. There is further encouragement in the fact that the Lindley track was virtually experimental, whereas the first few hundred miles of railway conversion will provide just the type of experience for which the Road Research Board has appealed[4] in order to round off the development of machines, techniques, and craftsmanship.

Altogether it seems not unreasonable to expect that road surfaces of the future can be laid to a standard of evenness comparable to that of railways and with the added advantage of being without joints. In any event there is definite promise of riding comfort far surpassing that of other forms of transport.

Speed is a natural concomitant with comfort. Even now, upon encountering the occasional stretch of road with an index of 60 in/mile

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[1] The references are given on p. 742.

motorists gratefully, though almost involuntarily, increase their speed by 5 or 10 m.p.h. But the greatest effect of all will be discerned by engineers and accountants, in that roads will never damage vehicles and vehicles will never maltreat roads. At present, rail traffic wears away 52,000 track-miles of permanent way to the tune of £38 million a year (excluding bridge and structure maintenance),[5] and road traffic does much the same to 190,000 miles of public road. Surely this is not economic in an age when the combination of pneumatic tire and truly even road surface is available. The cost of unnecessary damage to vehicles must be even greater.

Gradients

British main-line railway gradients seldom exceed 1 in 100 and the steepest is 1 in 37·7; [6] the entire system is virtually horizontal. Such route horizontality is unknown to road transport, but the subject has recently been investigated,[7] revealing how sensitive motor vehicles are to gradients; inclines, and even declines, can be equated to detours, sometimes of considerable extent. For instance, fuel consumption is trebled on an incline of 1 in 4. But a more pertinent revelation is that a certain ordinary modern car on a straight typically up-hill-and-down-dale route, between two places of equal altitude, can average at the best 50·7 m.p.h., fuel consumption being 26·1 m.p.g.; but if the route is levelled out the car averages 60·7 m.p.h. and fuel consumption is 26·5 m.p.g. The saving in time is to be expected, but the saving in fuel, being dependent on carburation, is a little more obscure. This is not the only instance of the costs of road transport varying inversely with speed. The effect is very much more pronounced with heavy vehicles, and there is patently a case for providing road users with this alternative horizontal roadway system, not only in order to save the time wasted in ascending gradients, but also to economize in fuel. Horizontality, which is an obvious necessity in rail locomotion, would act like a tonic on road transport vehicles, vastly improving their performance.

The disadvantage of road gradients is not confined to the intermittent wastage of motive power on gradients. Their effects can be traced back to the vehicle design stage.[8] A vehicle for use on normal roads must be able to climb 1 in 4 or 5, and so the designer is hampered in his efforts to produce a vehicle that is not extravagant when travelling horizontally. Once there is a complete inter-town roadway system of negligible gradient, on which a vehicle will be able to spend its entire life, it will become a commercial proposition to produce lightweight streamlined high-speed buses, lorries, and cars. Only then can the full economic advantages of level running be enjoyed. Conversion would therefore not only save conventional vehicles time and money, but would also lift vehicle design out of its present narrow groove. Perhaps not least among the potentialities of conversion is the creation of a field of employment for gas turbines.

Alignment

Public roads in Britain do not merely have corners. They have unsuperelevated corners. This is a shortcoming which no doubt has its origin in finance. In contrast the converted railways would have only curves, superelevated so as to feel straight to the driver at normal speed. This would bring great relief to driver, vehicle, and surface.

Furthermore, since the curves would never be abrupt, current legal restrictions on the length of vehicles, and on the use of trailers and semi-trailers,[9] could not justifiably apply to the vehicles specially designed for the new roadway system. Thus in the design of these vehicles it would be possible to match the long wheelbase of a railway coach, though the resemblance would probably end there : roadway vehicles would be patterned on aircraft fuselages, rather than rolling stock, both externally and internally.

The most significant factor, however, is that railway alignments often provide the shortest route between places. This gives scope for reducing the gross vehicle milage incurred in meeting the transport needs of the nation. In the aggregate the financial implications of this are enormous ; there has recently been instanced a potential capitalized saving of at least a million pounds in shortening a single trunk route by $\frac{1}{2}$ mile.[10]

Width

The Ministry of Transport and Civil Aviation's rule for new roads is that the normal traffic lane shall be 10 ft wide, but when a carriageway is to comprise only two lanes they shall each be 11 ft.[11] These dimensions take into account the extreme range of modern, uncontrolled traffic. And they do *not* apply solely to dual carriageways ; the Ministry even intend that Phase One of certain of their projected dual 22-ft motorways shall amount to no more than a single 22-ft carriageway.[12] In short, there is professional recognition of the 22-ft road as being of ample width. But the average car driver, who is probably not prepared to back his opinions with a tape-measure, is often dogmatic to the contrary, affirming that a double-track railway is not wide enough for a road. The Author ventures on this digression in the hope that engineers will educate the public in road widths and in the fact that double-track railways in Britain are never less than 24 ft clear width—often 30 ft at formation level. They would form roadways of basically three-lane width, intermittently of two-lane width. Often, at little extra cost, a fourth lane would be possible—as a lay-by if not as a running lane.

Single-track railways could readily be converted into sub-standard two-lane roads comparing favourably with minor public roads ; the expense of raising them to full 22-ft standard would no doubt be justified in some places.

At the other end of the scale, for surburban traffic there are lavish multiple tracks which would yield approximately $1\frac{1}{2}$ times as many lanes.

This lavishness is not confined to cities and their outskirts. For instance from London to Didcot the old Great Western Railway is quadruple track, broad gauge, of maximum gradient 4 ft/mile,[13] offering 53 miles of potential six-lane motorway. The entire railway system comprises quadruple track (or over) 1,507 miles; triple 447; double 10,351; single 6,969 (plus disused routes).[5] Only Belgium has more railways to the square mile.[6] On the converted British Railways' system drivers would at last experience true road spaciousness, in length and in breadth.

Intersections

On the B.R. system the counterpart of the multiplicity of road junctions encountered on public roads would comprise only stations, junctions, and level crossings.

Existing passenger stations would provide ready-made access to the system, conveniently located. It could be presumed that there are enough of them; their average distance apart is 3¼ miles. Their conversion would be a straightforward, though engrossing, engineering task. Junctions and level crossings would similarly present interesting engineering features, but at this stage it is only relevant that they are relatively infrequent on the B.R. system, and that, irrespective of fly-over possibilities, the passage through them of road vehicles would lend itself ideally to automatic light control—not a single signal-box should be necessary.

There seems no reason to suppose that intersections would seriously mar the perfection of the B.R. roadway system.

CAPACITY

The word "reserved" in the title of the Paper should be interpreted as meaning that only fast vehicles, regularly inspected for road-worthiness, would be allowed on the B.R. system. Drivers too would have to pass stringent tests. Mobile traffic police and an efficient breakdown service would be provided.

These conditions appear to complete the trio of excellences—routes, vehicles, drivers—that will yield the long-sought nearly perfect road system. Certainly it is hard to discern any factor that could seriously impair the theoretical lane capacity. The Author is content to put this at 1,000 vehicles per hour—corresponding to a vehicle spacing of 100 yd at 60 m.p.h., which he suggests would become the minimum acceptable journey speed.[14] However, American data indicate that traffic queues would not form below 2,000 vehicles per hour at 40 m.p.h.[15]

Lane capacity, however, is perhaps of no more than academic interest. Even at Waterloo Station, London, the gross daily quota of passengers is only about 200,000.[16] After conversion, 60-seater bus-trailer combinations dispatched at a rate of one every 1½ min, from each of Waterloo's 21 "platforms," will be able to carry away 50,000 seated passengers per

hour. This rush-hour flow of vehicles (840 per hour) would not amount to the full capacity of one single lane. Obviously there would be no bottleneck restricting out-going or reverse traffic beyond the station, or at Clapham Junction, where a great multiplicity of lanes would be available.

At ordinary stations, not served by tube, the capacity of the access roads could not amount to more than a tiny fraction of the roadway capacity; and it would take an extraordinary succession of stations to load even one lane to full capacity. In so populous a district the railway would have been multi-track.

Thus, even during rush hours, the demand could hardly cause any lane to run at full capacity, or even at half capacity. The significance of this is that the overall capacity of the roadway system would be vast—so vast that not even British Railways' recapture of much of the present road-borne traffic would be likely to result in their loading the system to more than a small percentage of its capacity.

Operation

It is the contention of the Institute of Transport that transport is not an industry but a service.[17] Its purpose is, more particularly, to serve the convenience of individual people. However, the bulk service performed annually by British Railways will be relevant as background to a brief outline of the services that would be possible after conversion. It amounts, roundly, to 20,000 million passenger-miles and 22,000 million ton-miles.[5] In terms of roadway operation this can be equated to the fully laden running of 10,300 vehicles at 60 m.p.h. for 8 hours a day, 6 days a week (totalling 2,500 hours a year for each vehicle), one-third of them being 40-seater buses, two-thirds 20-ton lorries. These figures should not, of course, be construed as any precise picture of what would happen. A vaster and very much more varied fleet (proprietary, subsidiary, or contractual) would be employed, and these powered vehicles would be supplemented by an abundance of trailers. But the Author suggests that given good organization, including driver relief and night running, many vehicles would achieve at least 2,500 hours a year at full load. A normal figure for aircraft is 2,700.[18]

Freight traffic

Freighting potentialities include the use of trailers towed in string by special high-speed motive units on the roadways. The trailers would be of legal dimensions so that they could be collected or delivered (by public road when necessary) individually, by conventional licensed motive units —a door-to-door service with no more than a change of horses. Demurrage on trailers could be low, encouraging clients to make up complete trailer-loads. Private ownership of trailers could be re-instituted with increased advertising value. Luggage compartments in buses, or luggage trailers,

could be used for parcels. All freight services would contrast strongly with the present railway service in speed and security.

First-class passengers

As the equivalent of first-class passenger travel there could be a hire-car service, and it might include self-drive by qualified clients. The cars would be specially designed for roadway use: to take them on to the public roads, where they would be taxed and traffic-jammed, would probably be uneconomical.

A typical passenger service

Passenger services will be illustrated by an example over a route of medium length. (It may be said that within the United Kingdom no distance is more than medium.)

Suppose that one day between 1 p.m. and 5 p.m. 800 people wish to travel express from Paddington to Bristol (118¼ miles, say 120), and 40-seater buses are being used. At 1 p.m. the next Bristol bus will be standing ready, and by perhaps 1.15 p.m. the first 40 passengers will have arrived, bought their tickets, and filled the bus, which will then set off, its place being taken by the next bus, and so on all through the afternoon. The average time between buses will be 12 min, the actual time varying perhaps between 2 min and 20 min. Allowing 2 hours for the journey, anyone Bristol-bound that afternoon will be unlucky if the journey takes him 2 hours 20 min from the time he happens to walk into Paddington station.

This illustration has been given for a route on which there is already a good train service, and the buses have been allowed to average no more than 60 m.p.h., in order to bring out only the chief element in serving the convenience of the public, namely frequency. The Author suggests that the "no time-table" principle should be mandatory, combined with specified maximum times of waiting for conveyance. Perhaps 40-seaters should be the largest buses allowed, and passenger-trailers forbidden except during the very busiest periods. The size of bus should then be scaled down to correspond with the volume of traffic between destinations. This may at first sound extravagant in drivers; but one irrefutable lesson of the conflict between rail and road is that if you attend to the public's convenience the economics will attend to themselves, and there is the further point that one driver at 60 m.p.h. is worth three at 20 m.p.h.

Toll traffic

To say that there would be ample room for toll traffic must be an understatement. Present traffic on British Railways amounts to approximately one-fifth of the whole, that on the public roads to four-fifths. If B.R. succeed in reversing these proportions the 10,300 vehicles mentioned above will increase to 41,200. Extrapolated at approximately four times

that number, the new fleets would amount to only one vehicle per furlong of route. But this is a highly complex subject, and perhaps all that need be borne in mind at present is that the crowding of a road is proportional not to passenger-miles or ton-miles but to vehicle-time. Without toll traffic these high-speed roadways might often have the appearance of lying fallow, and until the pattern of vehicle ownership alters, the claims of the owners of eligible vehicles to rent the system momentarily might be irresistible.

Economics

The economics of railway conversion appear to have been resolved already—unintentionally—within the Ministry, whose scheme for motorways, which includes 800 miles of new construction on virgin land, costing up to £200,000 per mile, has been affirmed economically sound.[12] They have established that it will be a paying proposition to spend £120–£160 million on constructing the 800 miles of new road. This is an amazing revelation of the true worth of good roads. It is the more amazing in that these particular roads will not run where they are needed most; that is, into the towns and cities. A professional debate on this point was effectively summed up in the remark that the sting of a journey is often in the tail:[19] between two medium-size cities 100 miles apart it is probable that the 5 miles at each end are of more account than the entire intervening 90 miles: there are twenty-nine principal roads at a 15-mile radius from the centre of London, and two-thirds of London's traffic is generated within that radius: at a 25-mile radius only one-quarter of the traffic comes from outside.

In viewing motorway projects one can therefore be very wrong in thinking chiefly of the open stretches. Perhaps one of the most important features of this conversion scheme, having regard to London's acute traffic problem, is that at a radius of 20 miles from Charing Cross there are thirty railways, serving thirteen termini not more than 2½ miles from Charing Cross. Moreover these railways form a network within Greater London, and at many places, including even places in the central area, they swell out into yards and sidings which would serve as car parks. If it is considered to be "economical" to spend £200,000 on a mile of road out in the country, then for the spending of about one-eighth (?) of that sum on a mile in a built-up area the word "economical" is hardly adequate: the value of parking space is indicated by the proposal for garages in London squares at a capital cost of £850 per car.[20]

So far in this Paper the project has been viewed mainly at close quarters. Taking a more comprehensive viewpoint the whole subject can be considered as a productivity problem. In any mechanized industry the price of the product and the level of prosperity are governed inexorably by the speed at which the machines are run. What would happen if looms,

printing presses, and other static machines were restricted to quarter speed? The answer is provided by London Transport's bus services: a rise of 1 m.p.h. in their average speed would save London Transport £2 million a year.[21] Further rises would have comparable effect, diminishing only gradually all the way up the range of vehicle speed; and the same applies in any bus or road-haulage service. Journey speed is the ruling consideration. This traces back to the elementary fact that wages and salaries are on a time basis, revenue on a milage basis. But that is not generally recognized; there is even a notion that speed is necessarily expensive. The Author has therefore given in the Appendix an analysis of the costs of vehicle operation on the converted B.R. system; a passenger fare of $\frac{1}{2}d$ a mile and a freight charge of $1\frac{1}{2}d$ per ton-mile appear practicable.

Furthermore, transport must be viewed as a service rather than an industry. Its own prosperity is of trifling account compared with the benefit to the community of full cheap efficient service. The precise effect can hardly be computed, but certainly about 12% of the national income goes on transport directly, and indirectly it has been blamed, though in a more extensive country, for from 30 to 70% of the price of things. In any event the healthy critical outlook is that transport always costs too much and takes too long.[22] British Railways have this outlook. They intend improving their service by capital expenditure over the next few years. There is to be some belated spending on roads, too. The outcome may be of the order of a 15% improvement in the efficiency with which railways meet one-fifth of the demand, and a 1% improvement for the remaining four-fifths. The Author diffidently suggests that, in a competitive world, this is not enough.

Manpower

Limiting himself to just one of the manpower aspects, the Author mentions again the expectation that 10,300 vehicles from among the fleets operating on the converted railways would be able to equal British Railways' present output of passenger- and ton-miles. The number of railway signal boxes which would be dispensed with also happens to be 10,300.[6]

Safety

Possibly the main point to consider is that the B.R. roadways will seldom be dual-carriageway. It is timely that there is just now a perceptible swing of professional favour away from dual carriageways; it is evident in discourses from the south,[23] the north-east,[24] and from Scotland.[25] Apparently oncoming traffic keeps a driver alert, and interested in his job, which may somehow be more desirable than the complete absence of oncoming traffic. In addition, on single roadways the central lanes can be allocated as required to suit the traffic flow, as happens in

Queensway (the Mersey tunnel), which is indirectly an extra safety measure.

Accident frequency (per million vehicle-miles) ranges from 13 or more on busy shopping streets to about 2 on lightly trafficked rural roads; on motorways abroad from 1·5 to 0·4.[26] The B.R. system will be superior to motorways in design and in control. But the principal factor is always the human one.[27] With screened drivers accidents almost cease. The B.R. frequency is almost certain to be less than 0·4; the Author suggests a potential figure of 0·04.

To minimize the mortality rate within the accident rate, rear-facing seats could be introduced. In the hire-cars this will eliminate "back-seat driving"—an insidious cause of accidents.

Finally, it may be thought that the Author is suggesting the abandonment of a safe form of transportation on rails. However, measuring in man-minutes (or man-yards) the part played by roads and pavements in the entire community's daily lives and comparing it with that played by railways and railway premises generally, the ratio must be at least 12. On that basis the two systems are equally safe. Some relevant statistics [28] are given in Table 1.

TABLE 1

	Killed	Injured	Total
Railways—for year 1952 . . .	415	26,114	26,529
Roads—for month August 1954 .	414	23,370	23,784

ENGINEERING

From the engineer's viewpoint railway conversion seems to present two major potentialities—or they might be called opportunities. First, it seems to offer the chance for British engineers to become world masters in a new and specialized branch of the profession, including the application of aerodynamics and electronics to land transport. Secondly, the project will provide a solitary instance of engineers working in full harmony with the countless authorities and societies that have to do with farming, noise, smoke, accidents, angling, rural scenery, and all the many other factors known as "amenities."

STRATEGICAL

It is perhaps necessary to anticipate the argument that experience in the operation of railways must be kept up to date in order that use could be made of railway systems in foreign theatres of war. This argument

implies that Britain should wait and follow the lead of other nations in railway conversion—and presumably in everything else. Britain led in railway construction.

But the home front seems likely to be the vital one. With all transport on pneumatic tires, and an extra 20,000 miles of high-speed high-capacity road available to it, there would be far greater readiness than there is at present to meet sudden emergencies, whether involving city evacuation the gathering in of fire engines from a distance, or any other movement. The means of transport would be flexible and, as a whole invulnerable— everything in the world is now vulnerable locally. The question of being dependent on imported fuel is hardly pertinent; Britain is already so dependent, even to the extent of having to import coal.

Prestige

Motorways abroad induce a feeling that Britain is perhaps rather backward as a nation. There is, as it were, an inter-nation competition in transport efficiency; and although Britain's old-fashioned roads are very good old-fashioned roads, British road engineering has been outstripped by expensive construction in other countries. Railway conversion offers an opportunity, the Author submits, of coming up from behind inexpensively, and taking the lead.

Conclusions

The philosophy of the matter can be summed up in the question of whether it is a good thing to save people time and money.

The latest of the many names given to motorways in other countries is "thruway." The Author ventures to suggest that in order to perpetuate the underlying "permanent way" idea mentioned in his opening paragraph, British Railways should, without more delay than is inevitable in the preliminary trial of anything new, secure the copyright of the word "trueway." Would not "British Trueways" typify the spirit in which this Paper is written?

The Author wishes it to be known that the opinions expressed in the Paper are his own personal views.

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APPENDIX

FINANCE OF VEHICLE OPERATION ON THE CONVERTED B.R. SYSTEM

A 40-seater bus, running fully laden, 8 hours a day, 6 days a week, on an express service at 60 m.p.h., will be considered first.

It is claimed that the above performance is certainly attainable and, in view of the following considerations, may indeed not be greatly above the average :—

(1) Traffic will comprise the entire former railway traffic plus an indeterminate amount attracted from the public roads, or of new creation. Its volume will justify most services being express ; only the short feeder services will need to stop at a succession of stations.

(2) Again the volume of traffic will normally enable the express buses to run full, not to timetable.

(3) The bus might take the form of a 20-seat motive unit, with 20-seat semi-trailer, and a further 20-seat trailer, so that it averages 40 seats or more in operation. One or both trailers could be discarded during non-rush hours ; they could also be used as "slip coaches." The flexibility of vehicles of this type will enable their "dead milage" and "idle hours" to be minimized.

(4) A wide range of modern inventions will contribute to the efficiency of the system. For instance : telecommunications in the overall control of the fleets of vehicles ; mechanical handling of freight ; radar for fog running ; new forms of braking, even air braking ; the gas turbine—and its suc-[illegible]

The chief items in the annual accounts of the bus might be as follows :—

Receipts

	£
Passenger fares :—	
40 passengers for 149,760 miles @ ½*d* per passenger-mile . .	12,480

Expenditure

Drivers—2,496 hours at overall wage equivalent to 10*s* per 60 miles (i.e. per hour at the wheel)	1,248
Fuel, lubricant, tires @ 3·6*d* per mile	2,246
Depreciation—say 25% bus, 10% trailers	1,000
Maintenance, servicing, dead milage, overheads	1,506
Total expenditure	6,000

The margin of £6,480 compares with that of two extant services as follows :—

Item	London Transport 1952 (9,847 vehicles)	Scottish Group 1952 (3,917 vehicles)	B.R. (potential)
Average annual gross receipts per passenger vehicle, i.e. coach, bus, or trolley bus	£4,930	£3,970	£12,480
Net —do—	£31 (loss)	£430	£6,480
Average fare per mile	1·38*d*	0·96*d*	0·5*d*

Whether net receipts on this scale would be sufficient depends on the policy regarding toll traffic. Road transport already pays £361 million a year for the use of public roads that get only £80–£90 million worth of attention; vehicle owners would get infinitely better value for money in paying tolls for the use of the B.R. system: possibly tolls would cover the entire cost of upkeep, and also make some contribution towards interest on capital—more than this is achieved in the Mersey tunnel. On the whole the standard ½*d*-per-mile fare is adjudged practicable.

It should be noted that the 40-seat bus can be equated to a 20-ton freight vehicle with "fare" 1*d* per ton-mile. However, dead milage is a greater factor in freight services, so 1·5*d* ton-mile is probably a fairer estimate of what would be practicable. The comparable British Railways rates for 1952 were 1·94*d* for minerals, 2·35*d* coal and coke, 2·69*d* all classes. The British Road Services rate was 4·03*d*.

The owner-driver of a 60-m.p.h. hire car, with fare 9*d* per mile (of which 3*d* goes at once on fuel, lubricants, and tires) would clear 30*s* per hour. If he could average 4 hours employment a day this would amount to £2,190 a year—enabling him to write off a £790 vehicle and remain £1,400 in pocket. The 9*d* fare therefore appears practicable; divided between four passengers it would be less than the present first-class train fare of 2·6*d* per mile (third class is 1·75*d*).

The foregoing examples of high journey-speed reducing the costs of transport are no more than an extension of current experience; an express railway service is normally very much more profitable than an ordinary one. But there are many technical and sociological factors limiting the proportion of railway services that can be express. From the financial viewpoint conversion can be seen as a means of vastly increasing the proportion of express services on the British Railways' system.

The Paper was received on the 6th January, 1955.

Discussion

The Author, introducing the Paper, paid a tribute to Mr T. E. Hutton, whose valuable work on the design and layout of motorways had been discussed at the Institution almost exactly 2 years previously.[12] That discussion had covered and disposed of many of the details of the present subject, and had also prevented it from seeming unduly iconoclastic; for the question had arisen whether Mr Hutton's motorways should be aligned alongside the railways, and now the Author proposed merely lifting them over the fence and putting them where he thought they belonged.

The main issue, presumably, lay between rails and a plain road surface, but the Author hoped that the ensuing discussion would not resolve into yet another debate on the rival merits of rail transport and ordinary road transport. His proposals were for a distinctive third form of transport which was truly an amalgam of the other two and, like any amalgam, it would finally bear no very close resemblance to either of its constituents, though it would have to preserve certain of their qualities. Which of their qualities would be preserved and which eliminated?

He proposed dealing very briefly with two or three of the qualities in question, starting with the low rolling friction of railways. That had been their vital characteristic when mechanical power was in its infancy. Brunel had based his advocacy of the 7-ft gauge on the axiom: "the larger the wheel the less the friction". He had intended constructing his carriages

between large wheels instead of over small ones, as was necessary with the standard gauge, and he had hoped thereby to reduce the tractive effort required to overcome friction between tire and rail from 10 lb/ton to perhaps 8 lb/ton. But today power was plentiful and cheap, and the Author suggested that neither financially nor technically did there remain any merit in the low friction of railways. On the financial side—to consider one form of power that was by no means the cheapest—one pennyworth of electricity disposed of the friction directly attributable to 700 railway-passenger-miles bringing in a revenue of 1,225 pence (third class). So the low friction was not reflected in fares, and indeed it could be halved or doubled or increased tenfold without affecting fares or freight charges. On the technical side, the stage had been reached where the abundant power now available in various compact mobile forms simply could not be harnessed effectively or safely without wheel grip derived from adequate friction between tire and running surface.

Research in Brunel's day had gone into minimum friction; today it went into minimum acceptable friction, which was virtually the opposite. Indeed, friction within reasonable limits had ceased to be an enemy and had become an ally. Hence the Paris Metro's quaint experiments with pneumatic tires. But it seemed that the optimum friction could be obtained only with pneumatic tires on a carefully specified road surface and, thanks to the Road Research Laboratory, everyone could be confident that one feature of the roads that British Railways might make of their permanent ways would be precisely that of optimum friction.

Next he wished to refer to the herculean task of railway-track maintenance which, it was predicted, would increase as a result of the £1,200 million modernization scheme. The reasons for the great disparities in expense and in effort between railway maintenance and road maintenance had been ably brought out by Mr Barnes in a Paper,[29] from which he would select just two of many relevant passages. First, Mr Barnes had deemed worth mentioning, enviously, the elementary fact that in modern roads rainfall was kept out of direct contact with the subgrade; and secondly, in dealing with the blanketing of a clay subgrade, he had admitted that vertically the adopted grading of materials was opposite to the conventional one met with in road practice. In short, the ballasted permanent way became a macadam road upside down; and it seemed only sensible, especially in the British climate, to reconstruct it the right way up as a road, when it would largely look after itself, changing the task of the permanent way engineers into one of high-grade road construction and maintenance—in which they should have no difficulty in achieving their declared aim of mechanizing their work.

But there was one valuable quality of railways that would be inherited lock, stock, and barrel by the proposed third form of transport, which was

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[29] References 29 *et seq.* are given on p. 787.

that it would be operated to professional standards, like sea or air transport, with none of the ragged amateurishness inevitable on public roads.

The Author had given three examples—wheel grip, route maintenance, and professional operation—to add to those already in the Paper of the manner in which the good qualities, and only the good qualities, of rail and motor transport would accumulate in the amalgamated system. The case for railway conversion could not be expressed in a phrase or a sentence. It was founded on a wide accumulation of qualities, which, on commonplace evidence, without allowing for improvements in road making and in motor vehicles, would yield a transportation system with the very minimum of imperfections. In fine, British Railways could become the sole purveyors of the highest quality of transport on earth if only they would abandon rails!

Rails had been a valuable expedient, for they had tided the world over a lengthy period when mechanical power had been scarce. They had done much for Britain, because British engineers had been the first to realize the potentialities of rails, whereupon the country's inland transport, through the medium of railways, had become so vastly superior to that of any other country that it had been able to play a predominant part in the nation becoming and remaining for a long time supreme economically among the peoples of the world. But now those railways had declined in usefulness to such an extent that their share of the yearly turnover in domestic transport was less than £500 million out of a total of more than £2,200 million. They had been outgrown and outmoded by the volume and pattern of the nation's transport requirements. They were indeed now no more than a sedate and orderly supplement to Britain's inadequate and crazy network of roads. They were now to be given an injection of £1,200 million, merely to keep them in being, carrying no higher a proportion of the nation's traffic for a period hesitantly defined as "many years to come".

Desiring to aim higher than that, the Author esteemed it a privilege to open an exploration of the one seemingly possible means of re-establishing British Railways as Britain's primary system of transport vastly superior to that of any other nation. Just as a century and a quarter ago the nation's well-being had depended on engineers realizing the value of rails, so today, against a totally different engineering background, including new sciences, new materials, new power units, new vehicles, and new road structures, much depended on their realizing the potentialities of the permanent ways as roads reserved for modern vehicles matching in excellence the road surfaces that could nowadays be produced by the civil engineering profession.

Dr W. H. Glanville (Director of Road Research, D.S.I.R.) said that after the Author's stimulating introduction of the Paper he found it somewhat difficult to know where to begin.

He thought that the main point to mention at the beginning was that unless the railways were revolutionized in their speed and efficiency or unless road transport was hamstrung in some way, by heavy taxation, preventive legislation, or inadequate roads (as might indeed seem likely from the rapid growth of traffic within recent years, for half a million new vehicles were coming on the roads every year and possibly in a few years' time there would be as many as a million new vehicles coming on the roads each year, if the motor manufacturers had their way), then the railways were wellnigh obsolete. If something was done to put the road conditions right, then the railways would have to revolutionize their speed and efficiency, and, as he saw it, the Author had suggested one way in which that speed and efficiency might, perhaps, be revolutionized.

In the Paper the Author had stated that he proposed to concrete over the railways and run special motor vehicles on them; the vehicles would remain on the concreted ways, with all the terminal difficulties that that would involve in the transport of goods and of people from the termini to the places for which they were destined. In other words, although the Author referred in passing to the "amalgam preserving the mercurial qualities of road transport", it was important to realize that his proposals would only partially do that.

The Author had not given what Dr Glanville would regard as really satisfactory figures of the cost of the conversion. The Appendix on "Finance of Vehicle Operation on the Converted B.R. System" was, to say the least, very optimistic. It did not seem to him that the sort of circumstances envisaged would be likely to pertain, namely, that buses would in fact run full for 8 hours a day, 6 days a week, and so on. He found it extremely difficult to understand how that could happen, and if it did not happen, and if for a large proportion of the time they were not full, then the whole argument was affected most seriously.

He would like to see some sort of estimate made of the cost of the conversion; he had no idea what it would be, and it seemed to him that the matter could not be properly approached until one had some idea of the cost.

Apart from costs, there were certain basic considerations upon which he would like to hear the Author's further comments. There was, in particular, the question of widths. He thought the Author was correct in saying that 10-ft-wide lanes *had been* accepted by the Ministry of Transport but wrong in thinking that they *were still* accepted. The Minister of Transport had already stated that the traffic lane on new motorways would be 12 ft wide, and that basically affected the Author's proposals.

The danger of traffic running in two directions on the same carriageway at high speeds was, said the Author, to be avoided by instituting high professional standards of driving. But Dr Glanville was not content with that because whatever was achieved in improving driving standards accidents would still be much more likely to happen on narrow carriageways

than on wider carriageways. He was surprised to hear the Author suggest otherwise; it was an accepted principle that two carriageways should be used. The temporary swing in favour of single carriageways was only barely perceptible and could not be seriously considered at the moment. The present real trend of thought was towards motorways which had two carriageways, one for traffic in each direction, with wider traffic lanes than those specified in the Paper, and—what was equally important—shoulders where vehicles in trouble could pull off. It was difficult, even under the ideal conditions of vehicle operation envisaged by the Author, to imagine a successful high-speed motorway without some provision for wide shoulders where the vehicles could pull off.

He did not think that the accident figures quoted by the Author were likely to be at all representative. The very low figures obtained on motorways abroad were attributable to very strict control of traffic—with police patrols, careful segregation of traffic, shoulders for the traffic to pull off, separate parking areas, and so on. In his view figures of that order would be very difficult indeed to obtain under the conditions which the Author visualized.

In his conclusions, the Author had said "The philosophy of the matter can be summed up in the question of whether it is a good thing to save people time and money." Dr Glanville suggested that the Paper did not prove that people would be saved time and money, but he suggested that the economics of the proposal should be examined in greater detail.

Mr David Blee (Traffic Adviser, British Transport Commission) said that he had long since recognized that the first qualification for a traffic man was to keep his mind absolutely open to receive the earliest impressions on any change in the methods of production of transport which were calculated to achieve the ideals of the philosophy expressed in the Paper.

He was not qualified to express an opinion on any of the technical facets of the plan proposed by the Author. From the traffic point of view, however, he felt that the Author had fallen into profound errors by not making as thorough a study of the traffic problem as he had of the technical issues. Without first fully assimilating the nature of the work which was required to be done, how was it possible to calculate the tools best suited to perform the task? It was impractical, he suggested, to think in terms of planning, for example, for the jigging and tooling of a factory without considering what sort of commodity it was going to produce, what the production cost would be, and to whom the commodity, when produced, was to be sold at a price which showed a fair return on the investment.

The traffic problem divided itself naturally into two parts, freight and passengers respectively, and he would treat briefly each of those parts and touch upon the generalities which were common to both.

The first point to be taken into account was the enormous peaks of the transport requirements in Britain—peaks which recurred by the hour, by

the day, by the week, and by the month. There was no evenness of distribution. For example, in the case of a large steelworks, the movements of coal, iron, limestone, and other raw materials in relation to the volume of finished products, might be in the ratio of 5, 6, 7, or 8 to 1; and it was certainly true that any transport system which could achieve a balanced load ratio of approximately 50% over its whole range of operations was doing something remarkably efficient.

He wished to dispel the false impression which, inadvertently, the Author's comments might have implied—that the railways were virtually an outmoded institution dealing with a residuum of traffic. The facts were that when the overall figures for road traffic were stripped of the work done by the collection and delivery vehicles of local retail tradesmen and short-haul operators, the work done on the roads in respect of commodities requiring public transport over measurable distances was 7,000 to 8,000 million ton/miles as compared with 22,000 million ton/miles by rail. Furthermore, the railways were by no means carrying the volume of business which they would be carrying under a modernized and reconstructed railway organization and with a rate-charging scheme which gave them the same flexibility as their competitors.

The Author had completely ignored the problem of the peaks—a problem which occurred with equal force in the field of passenger traffic. He had considered, by way of illustration, the requirements of Waterloo. However, a realistic calculation of the requirements of the London termini of the Southern Region at the peak hour of the evening would show that almost the whole of that proportion of the road vehicles allocated for passenger traffic would be required and none would be left for Manchester.

But that was not the only kind of peak. Football matches and other special events had to be considered. More important still was the peak of the holiday traffic. In fact, in the two months of July and August there occurred rather more than a quarter and nearly one-third of the whole of the long-distance passenger movement in Britain, and that had to be met by any provider of public transport, unless what the public required and what trade and industry needed were to be ignored.

Failure to make a really profound study of the traffic requirements of trade and industry and of the travelling public had led the Author into such profound error that Mr Blee did not think he was exaggerating when he said that the number of road vehicles of the capacity which the Author had indicated would be required in the traffic conditions peculiar to the country would be nearer half a million than the figure indicated in the Paper—and that should be considered in relation to the total staff at present employed on British Railways.

Dr Glanville had touched, in passing, upon some of those points and had stated in his concluding remarks that a profound economic study of the Author's proposals was necessary before conclusions could be drawn. Mr Blee had given some thought to the relative costs which would appear

to be involved in the two alternative means of dealing with the fundamental national transport problem. Of course, if it was practicable to relieve trade and industry of the cost of the transfer of traffic from one form of transport to another, a major contribution would be made to a reduction in transport costs; but if the Author's proposals provided the only way of doing it (which he would dispute), then, on the best calculations which he could make, the cost of movement under the present system of British Railways operation was likely to work out at approximately a quarter of the cost of movement under the scheme predicated in the Paper. The present cost of providing British Railways services was of the order of £500 million a year. That figure would be more than doubled if the Author's proposal was to be carried to its logical conclusion.

Nothing that one could foresee in the economic life of the nation over the next 10–20 years indicated any significant change in the fundamental factors of transport to which he had referred, and he therefore submitted that the Author's interesting, provocative, and helpful contribution to thought failed because the Author had not had the opportunity of making a sufficiently close study of the nature of the traffic problem and thus had been led into grave economic errors in his conclusions.

Mr Stanley Mehew (County Surveyor, Derbyshire) said that, as one of the "ragged amateurs" at present engaged in maintaining the roads of Britain, he was much intrigued by the Paper, the clarity of which made one feel that there must be a catch in it somewhere.

On the question of width and the necessity for dual carriageways, he entirely agreed with Dr Glanville's remarks. He felt, however, that primarily a major question of policy was involved. Knowing nothing about plans for the future of the railways, other than what he had read, he had assumed that it was envisaged there was to be a process of electrification, followed eventually by the use of atomic power and the development of cheap sources of electricity. That might make economic competition from vehicles of the type envisaged by the Author quite impossible.

He agreed that there was a possibility of converting a four-line railway into a dual carriageway road and thought that the engineering difficulties were probably less than appeared at first sight. In the first place, the very difficult problem of severance of properties—the cutting-off of the farm from its land, industries from their sources of materials, and so on—was overcome already, because those things had grown up around the railway system as it now existed.

It had been his lot to plan two roads of a much smaller character than those under discussion—roads about 10 miles long, in one case utilizing the line of an old canal and in the other following a disused railway. Compared with railways of the width now under discussion, those existing installations, the railway and the canal, had been very minor, but they had been of surprising value as a basis for planning modern dual-carriageway

roads; the detailed work in that connexion had convinced him that the change-over from rail to road would probably by no means be so difficult as many people might imagine.

The Author was probably right about the comfort, silence, and smooth-running conditions possible on a modern road system. But with long-distance traffic, even in the British Isles, he doubted whether the fact that people would be unable to walk about in the way they were accustomed to do in a train, would be welcomed by the travelling public. However that might be overcome by the trailer system with 8-ft or even wider vehicles.

He had some doubts about the Author's remarks on the subject of man-power. It seemed to him that if the commercial and industrial traffic were converted to a large number of small units, the manpower requirements must go up very substantially. He well remembered that during the war the proprietor of a very large road-haulage undertaking who, by a turn of fortune's wheel, had been put in charge of a very considerable coal traffic on both road and rail had told him how amazed he was at the ease of transporting large quantities of materials such as coal by rail.

He wished to make a point about the weather. The railed vehicle—the captive vehicle, as the Author had described it—was very much less affected by winter conditions of snow, frost, and fog, than non-captive vehicles. That was quite an important factor in certain parts of the country, because those conditions could persist for a considerable time.

After a careful study of the extremely provocative Paper, he had come to the conclusion that the Author had made out a case which justified a much more detailed analysis of the subject.

Mr John Ratter (Technical Adviser, British Transport Commission) suggested that if present-day scientific knowledge had been available 130 years ago, the railways would probably not have been built in their present form. Our forefathers might even have built motorways instead and the present meeting might now be bewailing the fact that the country was denied railways, with all that they could offer in speed, safety, and comfort, and with their potential to convert to the uses of transport future supplies of cheap electricity provided by nuclear power.

But nothing could alter the fact that the railways had been built, and even if there was advantage in doing it, the task of converting them to roadways was beyond the country's capacity in present times.

The engineering problem had been hardly mentioned in the Paper. Mr Ratter thought it was a fundamental mistake to consider conversion as simply laying concrete roadways on to formations where rails had lain before. A railway was far more than a system of tracks; it also comprised stations, workshops, docks, and many other buildings.

The engineering problem of conversion would also include the provision of road access to places where it did not exist—docks, workshops,

factories, and mines—which had been built on the assumption that the railways were there to serve them.

Further, during the period while conversion was being undertaken, the country's traffic must still be carried—and it should not be forgotten that most of the long-distance traffic was carried in bulk by rail.

When the railway from London to Edinburgh was being converted, for example, the whole of the traffic would be thrown on to the presently overcrowded route A.1.

The Author had not described the constructional difficulties bridges and tunnels would present. There were about 30,000 bridges on the railways, which, if they were to be used for roads, would in most cases be useful only so far as the main girders were concerned. Each would require a new floor.

Every station would have to be demolished. What would it mean, for example, to rebuild Waterloo to provide turning circles and a complete layout for buses?

Those were real difficulties, and it was necessary to be realistic in considering them. No one present needed reminding of the lack of engineers which the country had to face for many years to come.

The Author had stated that driving a bus at 70 m.p.h. against oncoming traffic on a 24-ft road would keep the driver "alert". He would certainly need to be. He would also be considerably frightened. If then, 24 ft was not wide enough, and the road had to be widened, then, since railways were built on high embankments and in deep cuttings to maintain easy gradients, heavy earthworks would result—far heavier than was usual in normal road construction.

Furthermore, railways ran over high-level viaducts and river bridges for the same reason. Widening them presented a formidable task.

The Author proposed the construction of roads with superfine level surfaces which would be very expensive to lay and to maintain against the dense fast traffic he envisaged.

It cost the railways £17 million a year to renew their tracks, of which about £6 million went in the purchase of new rail.

According to the Paper, 10,000 vehicles were going to run 2,500 hours a year at 60 m.p.h. to carry the railways' traffic. If that were so, each would have to cover 150,000 miles a year. On that basis the cost of tires alone would exceed British Railways' expenditure on rails.

Mr Ratter thought that comfort to the passenger did not depend on a level road surface alone. There was also the effect of steering. Even on the best road surface, soup could not be drunk in a car travelling at 60 m.p.h., a feat accomplished daily in trains!

He did not need to stress the effects of fog, snow, and rain on road traffic, for they were obvious.

He criticized the Paper because in his opinion it committed the error of being altogether too wholesale.

The railway authorities did not for one moment imagine that they should carry the whole of the country's traffic. They knew the important part the roads had to play in providing the nation with efficient transport and appreciated the need for better highways.

British Railways had launched an enormous modernization plan and were determined to carry it out. The Author should not think of railways as they were now. Two wars and their aftermath had arrested their development. The time could now be foreseen when trains would run smoothly on jointless rails at 100 m.p.h. and more, and passengers would sit at ease in comfort and safety, having their meals when they wanted them.

Goods traffic would be speedily distributed by making full use of the best features of both road and rail.

By all means let good highways be built, but let not the mistake be made of thinking that the best place to build them was on the railways.

Major H. E. Aldington (Technical Adviser, British Road Federation Ltd) thought that the Author had proved the case for a modernized highway system.

In the Paper there were certain references to taxation, but it was not perhaps generally realized that the motoring industry in Britain at present paid about £400 million per annum in taxation and, of that amount of money, less than 10% was spent on the roads. In the Paper reference was made to £80 million expenditure on the roads. That amount did not wholly come out of the £400 million, for about £40 million came out of taxation and the other £40 million came from the ratepayers. The £400 million represented about 2*s* in the £ of the national income, and was indeed quite a staggering amount.

He did not wish to refer to the question of the number of vehicles that would be required to run the Author's scheme, but it was interesting to note that at present the railway organization had about 19,000 locomotives, about 53,000 passenger vehicles, and about 1 million freight wagons. The utilization of those units had been fully discussed and criticized in a Paper[30] recently presented to the Institution of Transport.

Mr Aldington knew no one who really believed that a single 22-ft or 24-ft carriageway was adequate to carry heavy volumes of traffic. He thought the idea was quite preposterous. It was suggested in the Paper that the Ministry had agreed that certain roads should in the first instance be built with a single carriageway. That had not been for the reason that the single carriageway was justifiable; it had simply been on the ground of expediency—in other words, in some cases, to get a connexion through as quickly as possible with the limited amount of money which was available, it had been agreed that one carriageway should be built in the first instance. He personally would view with alarm any prospect of travelling at 60 m.p.h. on a single-carriageway road with traffic approaching at the same speed from the opposite direction—particularly at night with

glaring headlights. That was asking for trouble, as could easily be demonstrated by driving from London to Birmingham at night—it was quite a terrifying experience.

It was very necessary to be practical when considering new ideas. To refer to railways being in one plane—as compared with many roads, of course they were—was too facile. There was considerable curvature on many railway lines and it would be quite a useful exercise to take the length of railway from, say, Earls Court to Wimbledon and turn that into a road. Running over the viaducts approaching Putney Bridge Station there was only about 25 ft between the parapets, and the curves were sharp ; from an engineering point of view an enormous amount of money would be involved in doing the work.

With regard to tunnels, it would be quite impossible to get a 20-ft carriageway through an ordinary double-line tunnel. The headroom was all wrong, as indeed it would also be wrong on most of the older through-type railway bridges.

Mr Aldington found the Paper very interesting but felt that any money which was to be made available for roads should be spent on the scheme which had been prepared by Mr Barnes, when he was Minister of Transport, for a certain milage of motor roads which could be properly laid out. It was quite wrong to think that the newer roads which had been built recently had not been laid out properly, with regular curves and superelevation. British road engineers, contractors, and general suppliers of materials were well qualified and equipped to prepare such schemes and to execute them in a very satisfactory manner.

Mr J. B. Burnell (Operating Manager (Central Road Services), London Transport Executive) said that he would make one point only, because he believed that if there was agreement with him on that one point, there was no need to say anything more about the Paper. The point was not a technical one, but a human one.

He placed himself in the position of the driver of a vehicle on a 22-ft or 24-ft road, which it was known from experience had created on the high-speed roads in the United States a tremendous number of head-on collisions. He believed that in the United States 15 ft was recommended and almost insisted on between opposing carriageways on rural roads. He had recently had the frightening opportunity of riding on the eight-lane speedway outside Chicago where they reversed a certain number of lanes, allowing six lanes available for the traffic in the direction of the peak. He had been driving on the two lanes that had been left against the six lanes. Never in his life had he been more frightened and that notwithstanding, because of the head-on collisions, the fact that they had raised a 3-ft or 4-ft ramp between him and the oncoming traffic.

He believed that it was totally impracticable to ask drivers of road vehicles to drive along a road only 22 ft or 24 ft wide—and if his arithmetic

was right, about 80% of the railways were either single or double track, only a third being single track. He believed that the drivers would, quite rightly, refuse. He believed it would be absolutely and completely unsafe for them to drive on those roads.

In Britain there was tolerable weather only for a short time every year. There was every reason to expect 5 or 6 months bad weather and for 2 or 3 months there was every reason to expect fog and snow. Could one imagine a driver turning over to his relief and saying, "The engine is pulling well, the vehicle is loaded, there is ice and snow and fog ahead, but the radar is all right"?

Brigadier C. C. Parkman (a partner in the firm of Ward, Ashcroft and Parkman, Consulting Engineers) was pleased that the Paper had been presented by a Regular officer in the Corps of Royal Engineers, for there was much to be gained from the liaison of military and civil engineers in peace-time. Too often did it require a war to stimulate their joint contribution for the common good.

Brigadier Parkman himself had been trained as a railway engineer and was perhaps therefore a little biased; the Author would no doubt expect him to be critical. Even after reading the Paper he was not convinced that it would be wise to assume that the railway system's only contribution to the present-day transport problem was that of its right of way.

So many vehicles were already using the roads that difficulties in regard to the supply of petrol, oil, and rubber, all of which had to be imported, would have to be faced in the near future. It was generally agreed that the balance of the national economy would have to be preserved by cutting imports, and he suggested that the country would soon be forced to produce its own power for the propulsion of nationalized and public transport; that could be done by increasing the present supply of electrical power. With the development of atomic power, it would not be unreasonable to say that all the power needed for that purpose could be home-produced. He considered that one of the strongest reasons for retaining the railways was that they would accommodate a system of transport that could best make use of electrical power in its operation and control.

Brigadier Parkman could not agree with the assumptions which the Author based on the statistics given in Table 1. Even if the ratio of 12 : 1 in man-minutes or man-yards were accepted, the incidence of accidents was bound to increase when vehicles were travelling at 60 m.p.h. at 100-yd or 1½-min intervals, especially when visibility was impaired by rain and fog, or even during darkness. The drivers of the present trains—captive vehicles—were able to devote the whole of their attention to speed and signals, and in his opinion the present signal-box system was essential to the movement of large tonnages and large numbers of passengers. With electrical power and automatic control the number of signal boxes

could no doubt be cut down. Larger units moving at greater space intervals on their own tracks would appear to achieve the same movement of traffic with a greater safety potential. With the latest speeds achieved on the French railways, there would appear also to be ample future capacity on the railways. Two contributory causes of accidents were the human failings of the driver of the vehicle and the mechanical shortcomings of the vehicle itself. Both of those contributory causes were greatly magnified by the use of the proposed smaller trackless vehicle.

On the question of maintenance, he thought that, even with the improved alignment of the present roadways, repairs and reconstruction would be inevitable, and he suggested that those repairs and reconstruction could not be carried out without a greater loss of time than occurred on permanent way maintenance. The dislocation to the proposed reserved roadway bus timetable would, he submitted, be very much greater than that incurred by the modern railway train.

To sum up, whilst he agreed that the characteristics of roadways formed out of the present railway system would have much to commend them on riding qualities and gradients, he felt that, since an era of much faster rail traffic seemed near, operational safety could be best served by a transport system which would move with larger units on rail tracks at much increased speeds, rather than with trackless smaller units at increased densities. The captive-vehicle railway system should be retained for the movement of heavy tonnages and the movement of large numbers of passengers to and from the concentrated centres of population.

He concluded, however, on a note of limited concession to, and part-compromise with, the Author. The railways undoubtedly had been developed in the days of plenty by wealthy highly competitive 100%-private-enterprise companies who had been eager to offer services to the public and to capture every private trader's traffic. As a result the country had been left in 1922, when the railways had been grouped, with a multiplicity of lines. Many of those lines had been duplicated and more in the competitive era, and since nationalization some of them had proved unremunerative and redundant. He felt that in such cases serious consideration could be given, on grounds of national economy, to conversion and incorporation into the highway system.

Mr R. C. Bond (Chief Mechanical Engineer, British Railways Central Staff) said that on p. 740 the Author had referred very briefly to the question of manpower. It might be quite fortuitous that the number of vehicles which the Author had quoted, 10,300, was approximately the number of signalmen whom he suggested would be saved. As a motorist himself, Mr Bond felt that quite as elaborate a system of signalling as anything that was required on the railways would be needed to handle the sort of traffic that the Author envisaged. At Waterloo, for instance, with buses leaving from fourteen platforms in the morning or in the

evening at very frequent intervals, the signalling system would surely have to be very elaborate.

The physical difficulties of converting the railways to a road system had already been mentioned; there was, however, one point to which there had been no reference, namely, that at nearly all the principal junctions which were generally speaking at present laid out on one level he imagined that it would be necessary to contemplate fly-overs and a very elaborate form of clover-leaf construction in order to make it possible to keep the traffic moving in the way that the Author had suggested.

In any form of transport system fuel costs were most important. There was no information regarding the fuel costs of the 40-seater buses and the freight vehicles and trailers which would be involved, but—to consider for a moment freight traffic—he supposed that a fairly representative figure for a diesel lorry would be about 8 miles to the gallon for the 20-ton payload envisaged in the Paper. That would work out at about 65 ton-miles of work done per shilling expended, compared with 250 ton-miles per shilling of fuel costs on the railways as they were at the moment. Even if one assumed that fuel oil was available tax-free, the railways would still gain by a substantial margin.

Another point that should be remembered in connexion with the proposed roadawys was that all the fuel would presumably be imported, the use of electrical energy being precluded. It seemed to him that a system of transport which depended primarily on imported fuel and on imported material for the tires would be a precarious asset.

In the Appendix a 40-seat passenger bus was allowed 3·6*d* per mile for fuel, lubricants, and tires. That seemed to imply a very much better fuel performance than would in fact be possible if there was to be any money available for lubricants and tires.

In connexion with the figures quoted regarding the relative safety of the two systems of transport, he could not see any statistical meaning in the part played by roads and pavements measured in man-minutes, and it seemed to him that the position could be assessed only in relation to the number of people killed and injured per annum on the roads. He suggested that the figures used by the Author for rail casualties were unrealistic because the Author had chosen the year of the Harrow accident, whereas a truer figure could have been adduced.

To conclude, Mr Bond observed that the railways were not level, except relatively. But the vehicles, particularly the freight vehicles, that were to run on the motorways would have to be designed suitably to leave the main trunk routes and deliver their merchandise to all the many factories and establishments which at the moment were not on the proposed roadways. He therefore felt that some of the advantages of design which the Author had assumed would not be achieved, because if the freight vehicles were not taken off the "Trueways" and unloaded at the premises

to which the goods were consigned, there would still be a great deal of double handling into small consignments.

It was, of course, vital that the transport system should go on whatever the weather—so far as possible. At present, roughly half of the system—the railways—could and did function in any weather.

Mr S. B. Warder (Chief Electrical Engineer, British Transport Commission) gave the point of view of an electrical engineer. The Author had suggested a new approach to the transport problem, presumably on the assumption that the present methods had failed, and he implied that a colossal expenditure would be involved in the change.

It seemed to be generally accepted that steam had had its day and would give way to diesel or electric traction. He believed that in Britain the best future lay in electrification. It would therefore be interesting to test the Author's views against the modern alternative which might come quite soon.

The arguments against electrification during the past 25 years had rested mainly on the heavy first cost of the fixed equipment. So long as labour costs and material—for example, coal—had been cheap, there had not been such an enormous incentive to become involved in such expenditure. However, the conditions had changed, but even so he did not think it was generally appreciated that the cost of building an electrified railway was only 10% higher than the cost of building a railway without fixed equipment for electrification purposes. The question was, therefore, what could be had for spending 10% more when building a railway?

First, prime movers could be taken off the rails entirely. The Author had referred to the 20,000 vehicles that would be required under his proposal, although other speakers had suggested that ten times as many would be needed. But removal of a prime mover eliminated all the trouble that accompanied a prime mover. (He was himself an electrical engineer and no doubt Mr Bond would not agree with him entirely, but he thought that most of the trouble was mechanical and not electrical.)

The ultimate result would be a system of reversible trains running at any desired speed.

The question was raised nowadays whether locomotive drivers were getting a proper incentive. He did not know what incentive they would want for driving the Author's lorries! But with the possibilities that electrical engineering offered, it was quite likely in the future that the trains could set up their own route and really run automatically. Aircraft could now take off and land by radar; he did not want radar, for he felt that control could be much more efficient with rails to guide the vehicles; but by electrical means it would be possible to save a great deal of labour not only in train crews but also in the systems of signalling which the Author had suggested would still be required by his proposals.

A locomotive or a train was a power-conversion unit. All that it required was electric motors to convert the energy provided from the main supply system. All the trouble was taken off the system and put either on the side of the railway or handed over to the British Electricity Authority. The extraordinary thing was that the Authority did not have to provide an additional prime mover. The rate of expansion of the Authority far exceeded the rate of expansion in the railway electrification programme. New generating plant was being installed at the rate of 1,500,000 kW a year, and electrification could be done only at a rate requiring power at approximately 30,000 kW a year. Moreover, the power would not be wanted at the peak of the electricity supply period, so it would not be necessary to pay the maximum charge on all the traffic that was operated outside the peak periods in the morning and in the evening. It would therefore be a welcome proposition to the Electricity Authority and it would improve the load factor for the whole country. He suggested that no Government interested in the nationalized industries could afford to ignore such a possibility.

The country, he suggested, must look more to electrification as time passed and if the most was to be made of the country's resources. Since rail transport was a right and proper field which had been well exploited elsewhere, he had no reason to suppose that electrification would not be a better proposition than the one proposed by the Author.

Major J. E. L. Carter (Senior Instructor (Officers), Electrical and Mechanical School, School of Military Engineering) said that in his belief the Author was right, although not necessarily right in every detail and although the proposals made in the Paper were not necessarily the best in every way for everyone. Inevitably there would be disadvantages and difficulties associated with the disappearance of one form of transport, as indeed there had been in the past when previous forms of transport had been replaced by more modern developments.

The issue, however, was the fundamental one whether the Author's proposal was worthy of serious study, and Major Carter agreed that it should be carefully and independently examined and that the costs of the proposal should be carefully evaluated.

He thought that one of the points which made the proposal so significant was that Great Britain had grown up around the railway system, as the flesh on a body grew around the arteries and veins; and to the majority of cities, docks, and industries the railways, in their situation and functioning, were completely organic. Like arteries, they ran where they were wanted, and they were distinct from the flesh through which they ran. On the other hand, the roads, such as they were, were hopelessly intermingled with the body they were trying to serve, and the problem of making a road system was to provide access to and from the centres of population.

Although the economic experts said that the proposals were uneconomic and that the Author's traffic estimates were wrong, the fact was that there was a greatly increasing tendency to use the roads because, for many kinds of goods, road transport was cheaper in spite of petrol tax, purchase tax, and road-fund tax.

It therefore seemed to him that if some organic change was to be introduced into the transport system, then some use had better be made of the space now occupied by the railways. The wisdom of converting the whole railway system into a road system was arguable; perhaps part conversion was the answer; but he did not believe that a good road system could be developed without taking some of the space occupied by the railways.

He did not think it would be as difficult as might appear at first sight. Conversion should start at the coast, taking out of action about 30 miles of railway line; a transfer station should be created, at the change point; passengers could then transfer to conventional buses, and freight could be transferred quite readily with the use of modern mechanical handling equipment. When that 30 miles had been done, a further section of track could be taken. The process would have to be a gradual one, but he did not think it would be as difficult as some speakers had suggested.

He believed that the near future would show a diminution of the need for heavy traffic, arising from the development of the super-grid for handling electric power, the reduced availability of coal, the extended use of coastwise shipping, and the siting of power stations for service by water as opposed to rail. Inter-city air transport would also tend to draw off certain types of high-quality passenger and freight traffic. Those factors should be considered when assessing the value of the railways in 20 or 30 years' time.

There was, therefore, a good case for a very careful examination of the Author's proposals, and he thought there would be no *fundamental* difficulty in trying them out. The alternative seemed to be to carry on as at present with the two constantly improving systems, but with the railways continuing to lag behind because of their lack of flexibility and the road tending to lag behind the needs of the day because of its inability to get into the areas where the road communication was really needed.

Lt-Col. S. M. Lovell (County Engineer and Surveyor, West Riding of Yorkshire) said that he spoke as a highway engineer, and perhaps also as rather a heretic. He agreed partly with the Author in that Britain's great need was for the co-ordination of road and rail transport. Was it heresy to suggest that the way to do it was to build roads over the railways and to electrify the railways?

From the point of view of gradients, the railway locations were ideal. He knew the argument that the area of land required to build brand new roads would not represent a major problem, but with the suggestion that

he had made no new land at all would be required. Another point to be borne in mind was that if the roads were to be built over the top of the railways, there would already exist throughways through the provincial towns, and the colossal task of having to pull down property would not arise.

The value of the tourist industry at present approached £60 million a year. If the roads were up in the air, that figure might increase quite considerably, because the tourists would be able to see and to enjoy the country wherever they might go!

From the strategic point of view and the point of view of vulnerability during war, he thought that the Author would agree with him that if ever, unfortunately, there should be a war there would be such hydrogen-bomb devastation that it would not matter where the roads or the railways were.

In connexion with the construction of roads over railways, no costs had ever been worked out, although various costs had been suggested. He suggested that if the proposal could be tried out between, say, London and Birmingham on the best route possible over the railways, and if engineers really applied themselves to the design of factory-produced standard pre-stressed concrete units, the costs would not be so formidable as might be thought. In any case, so far as the present projected motorways were concerned, it had been very interesting recently to hear Sir Owen Williams say that a proportion of between 25 and 60% would have to be up in the air in any case because of crossing obstructions, rivers, canals, and railways. Why not the other 75 or 40%?

Mr H. J. B. Harding (Director of John Mowlem & Co., Ltd, Contractors) said that contractors were neutral, for they hoped to be able to help to spend some of the £1,200 million either on the railways or the roads.

As the Author had pointed out, the rail had been invented 400 years ago to ease the labour of horse and man by reducing friction. The invention of the locomotive had speeded up the movement so much that roads had become very secondary, and had started the age of railways. The roads had now recovered their position, not through the discovery of oil and the internal combustion engine, but by the discovery of indiarubber, which made it possible for engineers to build roads relieved of the pounding of wheeled vehicles.

The combined effect of those inventions, together with telephone, radio, and typewriter, had been to introduce the "Age of Impatience". Simultaneously, by the development of very powerful plant, instead of the principle of least resistance, there had been substituted the principle of brute force.

The Author's critics said that his proposals—apart from difficulties of width—fell down when they reached a tunnel. But from recent experiences

in Bo-peep and other tunnels it was more likely that the tunnels themselves would fall down, for most of them were 100 years old and in need of much maintenance. The Author's retort could be that with a motor vehicle it would be possible to build a by-pass and climb out of the cuttings and skirt the tunnels, if that were more economic than enlargement.

It was of great importance in the Age of Impatience for materials to be delivered to their destinations without re-handling. If Brunel had had his way, and if his broad gauge had been adopted, the Paper might never have been written, for the railways would have been big enough to carry road vehicles upon special trucks, which could then complete their journey by road.

All the docks in Britain had been designed for railway traffic, but now most of the freight arrived by road, causing great congestion.

People in Britain liked freedom of movement and were quite undisciplined in the matter. Dr Glanville was right in his warning that when everyone owned a car, everyone would be brought to a standstill. Wide vision had to be brought to the problem. In the past "reckless economy" had been our downfall. By fear of spending money we had been forced to waste in other ways.

In 30 years' time the new locomotives to be provided out of the £1,200 million would be obsolete. Now was the time to think as far ahead as that, and whether one agreed with the Author or not, his challenge was a valuable shock to complacency.

In the past the railways had killed the canals for their own gain, a folly from which the country had suffered in time of war. Whether or not it would be a just retribution to turn the railways into reserved roadways, or if it would be another folly to destroy a national asset, was food for thought.

The Author had brought a storm of opposition about his head. Some contributors had been wide-minded; others had, like the railways, run on narrow lines. It would be interesting in 30 years' time to re-read the Proceedings in the light of future developments.

Mr Alfred Goode (Deputy Director of Works, Air Ministry) said that the Author had not emphasized sufficiently the enormous benefit which would accrue to industry by a door-to-door transit of goods. The double, treble, and even quadruple handling which at present was necessitated by the railway system would be eliminated by freight vehicles loading up at a factory or a warehouse and the goods being unloaded at their ultimate destination. Vehicles on inter-town runs would perform the major part of their journey on the new roads, but would be free to leave them and use the present roads to arrive at their unloading point.

He was not clear whether the Author intended to segregate traffic on the new roads. He would suggest that only vehicles holding a commercial licence and public service vehicles should be allowed on them, leaving the

present road system, apart from the terminal journeys of freight vehicles, almost entirely to the private motorist. Whether, however, fast-moving public service vehicles should be using roads at the same time as comparatively slow-moving freight vehicles was a moot point, although the Author envisaged the build-up of a fleet of fast-moving freighters. If the roads were divided into lanes of various speeds, such as the Author had instanced in the Mersey Tunnel, Mr Goode believed that no real difficulty would arise owing to disparity in speeds.

Another point which the Author had mentioned was that of fuel. It was thought in some quarters that the railways were essential to Britain in time of emergency and that that viewpoint was given more power by the fact that, generally speaking, they used an indigenous fuel—coal. To convert the system into dependence on imported fuel might, to the holders of that view, seem suicidal; but he looked forward to the development by British manufacturers—and he was sure they could do it—of a fleet of economical "steam wagons" which in the past one had seen in large numbers on the roads and which were now rare owing to taxation. Their contribution to atmospheric pollution by smoke would be very small, and that argument against them would be completely nullified by the fact that they would be using fuel obtainable in Britain.

Turning to the engineering aspect, he thought that 50,000 track-miles of railroad were capable of conversion into the equivalent of 11-ft-wide traffic lanes. That meant that the construction of the enormous area of 323 million sq. yd of pavement was necessary to convert the rail system into roads. Was that figure, however, really formidable? The average large military airfield had about 1 million sq. yd of pavement, and one in Britain had—or soon would have—a paved area of 1,400,000 sq. yd. So the problem was, in reality, only that of building the same pavement area as 300 large airfields, for which most of the earthworks had already been carried out. Furthermore, the road pavements would be thinner, having to carry a much lighter load, and the problem was reduced to that of providing the equivalent of something considerably less than 300 airfields. The work necessary would include provision for additional drainage, enlarging or uncovering the comparatively few tunnels, removing platforms where necessary, converting sidings into parks, etc. (including all preliminary surveying, soil testing, and design). He estimated that the cost, allowing for a single-wheel load of 10,000 lb. would not exceed at the outside £1,000 million. He was confident that it could be carried out in 10 years at the rate of £100 million per year. That would not strain the resources of those public works contractors accustomed to the paving of airfields; in fact, he was sure that a referendum among them would produce the result that their combined resources could easily build twenty, if not thirty, airfields per annum. The planning of the sequence of conversions would, of course, require a very great deal of thought to

prevent disruption of services in a change-over, but the problem was by no means insuperable.

The Author had mentioned the riding qualities of the converted roads. Mr Goode's opinion, based on experience with aircraft, was that a concrete surface would not be good enough. Modern aircraft with high tire pressures were peculiarly susceptible to unevenness in an airfield surface and when they were required to run at speeds in excess of 15 m.p.h. it had been found that concrete was too rough and that a blacktop surface was preferable. It might be interesting to note that the present specification for airfield surfaces was that the deviation from a plane surface when tested with a 10-ft straight-edge should not exceed $\frac{1}{8}$ in. Profilometer tests had recently been carried out on two fields which had been strengthened and resurfaced about 18 months ago. The specification in those cases had been that the deviation from a plane surface should not exceed $\frac{1}{4}$ in. in any direction when tested with a 16-ft straight-edge. In both cases the irregularity index measured after the fields had been in use for 12 months had been less than 40 in./mile. Thus, it was clear that the riding qualities could be obtained by British contractors working (in those particular cases at very high speed) with a blacktop surface.

Despite the example of the Lindley testing track, he was doubtful whether those riding qualities could be obtained with concrete, even if the joints were sawn, which, he remarked, was extremely difficult with gravel aggregates. With rock aggregates, depending, of course, on the hardness of the rock, sawing joints was very costly, owing to the great wear on the saws. On the other hand when contraction joints were formed by vibrating a bar into the concrete, the concrete thus displaced produced a surface irregularity. At expansion joints also, despite care taken in their formation, an irregularity always occurred, and in his experience, after many miles driving in countries all over the world, plain concrete roads had not as good riding qualities as those with blacktop finish. He would recommend, therefore, the adoption of lean-mix concrete slabs, surfaced with blacktop using both bituminous and tar binders, thus employing three sections of the nation's paving industry to spread the load.

In conclusion, since the proposal to convert the railway system was of such importance and, in his opinion, so practical and potentially so beneficial to the country's economy, he suggested that the Institution, being the senior one in Great Britain, should set up a committee to consider all aspects of the problem.

Mr A. A. Osborne (Resident Engineer for Messrs J. S. Wilson and John Mason) said that there had been a short period before the 1939–45 war when dual carriageways had been built, or such appropriate future width provided, on many improvement schemes on what were then called Class 1 roads, because, irrespective of traffic capacities and traffic densities, it had been believed that dual carriageways were essential for safety. The

adoption of trunk roads by the Ministry under the Trunk Roads Act had enabled the Treasury's increasing stranglehold on main-road-improvement expenditure to cause the death-rattle of realistic highway improvement. Incidentally, the Author's references under "Safety" on p. 740 could not, in Mr Osborne's opinion, be considered as supporting a swing of professional favour away from dual carriageways; the road widths given in Road Paper No. 42[12] were the figures which should be adopted when considering safety. They stipulated an overall highway width of 88–93 ft with dual 22-ft carriageways and 15-ft verges; if that width was radically reduced to a 6-ft central strip and only 5-ft verges, the minimum then became 60 ft. The formation width of double-track railways was 30 ft, reduced to 19–22 ft in tunnels and deep cuttings with retaining walls, whilst the quadruple track was only 55 ft wide. It would be seen, therefore, that the 30-ft double-track width was the bottleneck (ignoring the cost of tunnelling, etc., for even narrower widths), which would allow only a narrow 22-ft carriageway without the important visibility allowance of verges and increased carriageway widths on bends.

It was agreed that the railway alignments were a great improvement, but there were bends on some main lines of 10 to 20 chains radius, particularly through stations, whilst the motorway standard was 2,865 ft minimum radius, with 1,508 ft in hilly country.

The Author had therefore adopted the smallest highway widths, which would, from the safety aspect, put his new B.R. system back to conditions that were becoming intolerable on the present highways. High-speed motor travelling demanded ample road widths for overtaking, good horizontal visibility—the vertical visibility of the railways was of course ideal—and a safety roadside margin.

Referring to the Author's remarks on superelevation (p. 735) the converted railways would have to be cleared down to formation level to construct a road and the formation was usually level, for the 6-in. maximum superelevation per track on railway curves was made up in the ballast. The reference to automatic traffic-light control under "Intersections" on p. 736 was surely a retrograde step which would soon upset the 51-m.p.h. average mentioned on p. 738 for the London–Bristol journey.

The statistics quoted under "Safety" in Table 1, p. 741, were not wholly applicable, for the comparison should be strictly between road and rail accidents. As was well known, the railways had had a very low accident mortality record before the war, and the figures in Table 1 for killed included 163 passengers, the remainder being railway servants and 52 others. Similarly, the injured total of 26,114 included only 8,297 passengers. The year 1952, however, was exceptional for it included the Harrow and Wealdstone disasters which had caused 112 of the 163 deaths mentioned.

The Author had laid much stress upon new opportunities for better roads with smooth surfaces but Mr Osborne could not understand why they

should be any different from the surfaces provided on new roads elsewhere. The very flat railway gradients would, in road engineering, present some difficulties because a gradient of less than 1 in 200 was unsuitable for normal surface-water drainage in a road channel and would necessitate a series of short reverse channel grades causing unevenness in the channels in order that water could reach the gullies. Consequently, the riding conditions in the channels would be worse than on a normal road where self-cleansing gradients made such expedients unnecessary. It should be realized also that the increased run-off arising from the large area of impermeable carriageway meant a completely new and larger drainage system. Such problems were small, however, compared to that of the method to be adopted to construct the new roads; could the Author explain how such roads could be built while the railway system was maintained until the roads were ready for traffic? Both the passenger and freight railway traffic could not use a single line, or double tracks on quadruple track lines, while half a roadway was being built. Even if that was possible, road engineers would shudder at the thought of building 20,000 miles of modern highway with only half the formation or sub-base being formed at one time and having a foundation construction joint in the centre. Such restricted conditions would not give sufficient clearance for up-to-date mobile road-making plant nor any material or plant storage space where verges were non-existent. Mr Osborne considered that it was not practicable to build a road on a railway track until trains and track had been removed. Except in rare situations where there might be an alternative railway route, railway services as they now exist could not be maintained while conversion to roads was taking place. Did the Author consider that the country's communications economy, apart from the consequent risk of no rail communications in the event of war, could stand the chaos that would be inevitable? For those reasons Mr Osborne thought that conversion of the British Railways system into a reserved roadway system had no potentiality because it would be economically impossible to make such a conversion without dispensing with railway services while each portion was being converted.

Turning from the possibility of conversion to its desirability, Mr Osborne said he personally preferred to make a long journey by rail and felt that railways were essential and had a permanent place in the country's communication system. As with other motorists he had long felt that too much heavy material travelled by road, causing delay, frustration, and accidents, when the interests of the country could be better served by a greater use of railways as the main means of freight movement. He recommended the banishment of long so-called indivisible loads from the roads; that there might be no railways to which such loads could be transferred was a thought sufficient to cause a motorist's nightmare.

It was interesting to note that *The Times* of 25th April had reported very satisfactory results in the operation of new lightweight diesel trains,

giving considerable increases in the passengers carried and receipts increasing up to 40%. That foretaste of what might be expected under the British Railways' modernization plan would simplify the road engineer's problems, for modern roads with the ever-increasing vehicle registrations needed some relief from traffic that should use the railways.

It was the variation in speeds that necessitated wider roads than those envisaged by the Author and by segregating the bulk of heavy freight traffic to railways, new roads would become faster and safer without the change-over chaos and doubtful economics of adding a reserved roadway system.

In conclusion there might well be sections of disused railways or minor uneconomic lines without freight traffic that could be dispensed with and adopted to form road by-passes or link roads. The use of abandoned railway permanent way, widened if necessary to suit safe roadway widths, had been and perhaps would be made in the future and Mr Osborne hoped that the Paper would be a reminder of such limited potentialities of converted railways.

Dr A. W. T. Daniel (Lecturer in Civil Engineering, Queen Mary College, University of London) referred to the speed of 60 m.p.h. and said that it was not quite clear from the Paper whether the Author was thinking in terms of cruising speeds or of start-to-stop averages, which were quite different propositions. If the former, then presumably the start-to-stop averages would be of the order of 50–55 m.p.h., which would imply a timetable of approximately the same standard as that of 1914; in fact, it would show no improvement on that of 1900; and it was sincerely to be hoped that there was no intention of spending hitherto uncalculated millions of pounds in order to revert to the position as it had been 40 years ago.

If, however, the latter was intended then the standard implied would hardly reach that of the current timetable, and would fall far short of that of 1939, when in Britain alone there had been more than 200 trains booked at start-to-stop averages of between 58 and 72 m.p.h. Those figures were for orthodox steam operation and by no means represented the limit of possibilities, as was evident from Fig. 1, in which all forms of motive power were represented, as well as several countries—Great Britain, the United States, France, Germany, and Italy. Some of the information was difficult to obtain, and he would be glad to hear of any amendments or omissions.

Record maximum speeds were shown by the full line, and it was surprising to find that so long ago as 1903 a German electric train had reached 130 m.p.h.; that had been a military operation and had been kept secret until many years had elapsed. In 1931 a German petrol car driven by a propeller had reached 143 m.p.h. but the idea had not been pursued, since the use of a propeller for a land-based vehicle had been considered

undesirable. The graph showed a reversion to orthodox diesel and steam at points 4, 5, and 6, and it was interesting to note that the record of 151 m.p.h. by a French electric train in 1954, shown at point 7, represented normal progress when previous history was taken into account. But the most recent speed of 206 (point 8) achieved in France would appear to have been reached 10 or 20 years before it could reasonably have been expected, and was therefore a great achievement on which the French authorities should be congratulated.

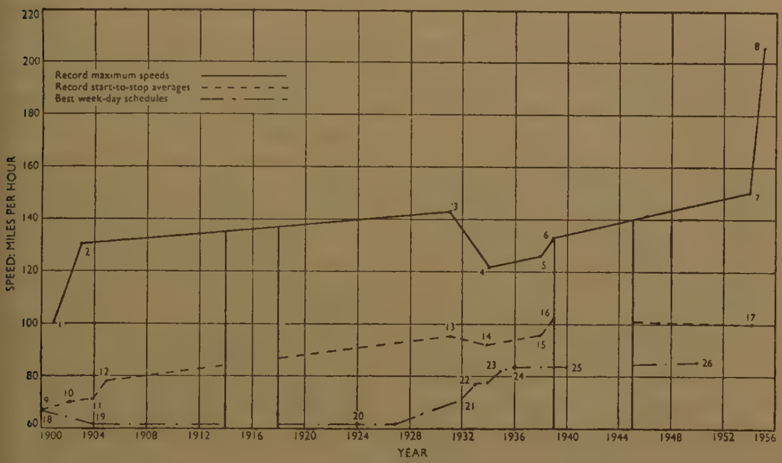

FIG. 1.—RAILWAY SPEEDS

The dotted lines showed the record start-to-stop averages, and the most significant was shown at point 16, when in 1939 an Italian electric train had run 196 miles in 115 min, giving a start-to-stop average of 102 m.p.h. That had so far not been beaten, and indicated the obvious direction in which future progress should be made.

It was obvious that to achieve a high speed in a specially arranged test was one thing, but to achieve it throughout the year in normal service was another; hence the chain-dotted line showed the best scheduled weekday averages. It was evident that records did eventually have an effect on schedules, but what was not shown by the curve was the general effect on the whole service. The handful of trains of which point 20 was the best had grown to large proportions; the 1954 French timetable had involved 329 runs at start-to-stop averages of from 60 to 77 m.p.h., and in the United States the similar figures for 1950 had been 2,500 runs at from 60 to 86 m.p.h. It would be appreciated that start-to-stop averages in the higher ranges required running speeds of 90 to 100 m.p.h. The totals for Europe and the United States so far available amounted to about

3,270 runs between 60 and 86 m.p.h. involving a daily milage of 182,000. The figures were smaller than they might be because those for Britain and Germany were well below the figures for 1939. It was evident that no one had attempted a statistical analysis of the schedules between 50 and 60 m.p.h.

Reverting to the French record of 206 m.p.h., the effects would be felt in the future. To Britain, the significance was that in the existing conditions and the distances between cities as they were, the challenge by the railway to the air could not be ruled out. The curve of progress was steepening; if it was true that a busy industrial nation such as Britain could not afford to stand still, how much the more could it not afford to go backwards. The world stood on the threshold of another great railway era, and any scheme, no matter how superficially attractive, which denied the nation its fair share could not be considered.

Mr Nigel Seymer (Editor of *International Road Safety and Traffic Review*) thought that a very good point was made on p. 739, where the Author had pointed out that motorways as at present planned would not run where they were needed most, namely, into the towns and cities. Personally, he felt that plans had to be made to extend the motorway system into the main towns and cities, and he considered that, although a wholesale abandonment of the railways was not at all indicated, possibly the only feasible and economic way of bringing motorways into the centres of the larger cities, such as London, would entail in some cases putting the railways underground and putting the motorways on the railway viaducts. For instance, the lines serving Charing Cross and Cannon Street could be put underground. According to his arithmetic, only two underground lines would be required to replace those surface lines. There would then be a right of way for a four-lane motorway which would go right to Charing Cross, and it could be continued from there right across the centre of London, partly in tunnel.

He suggested that if any committee were to be set up to go into the Author's proposals, special attention should be given to the possibilities of building motorways in place of railways in the big cities and linking up the suburban lines—having electrified those that were not already electrified—underground right across the central area, which would also improve the public transport system.

*** **Lt-Col. H. Cartwright-Taylor** (Instructor, School of Military Engineering) observed that there appeared to be two separate questions in the discussion. Was such a change practicable, or even possible, and if so would it be to the advantage of the nation?

Previous contributors had produced figures to show that the change, although a major task, would not be too much to undertake in a period

*** This and the following contributions were submitted in writing after the closure of the oral discussion.—Sec.

as short as 10 years, and that its cost might be of much the same order as that of the present proposed re-organization. Much of the work, after all, such as rebuilding tunnels, stations, and other installations, would be needed in any event.

Regarding its desirability, he thought that there were two points which many speakers in their desire to maintain the *status quo* had overlooked. First, the Author's proposal was for a "reserved" roadway; it would be presumably operated at one speed or at differing speeds on differing occasions. There would be no overtaking, unregulated stopping or turning. Of course, there would be operating difficulties, but they would be far less than those of a railway. He could not really see that nervousness was more likely to attack the drivers of the trucks and buses than the drivers of two French trains approaching at a relative speed of 400 m.p.h. Secondly, the Author's real plea was that railway operating methods limited the capacity of the route to far less than what it might achieve under his system. Nowhere in the Paper was it stated that the British Railways present traffic would be carried by 10,000 road vehicles. What the Author had, in fact, said was that 10,000 vehicles on a road operating under not very difficult conditions, could carry an equivalent to British Railways. He admitted that there would be many more than 10,000 or 20,000 vehicles. Special traffic problems would, of course, demand special solutions, but even when they had been solved there would still be plenty of room for more.

Some speakers had made much of the weather conditions—frost and fog—maintaining that they would put out of action any system such as the Author proposed. Lt-Col. Cartwright-Taylor thought it should be remembered that it was not many years since railway operators overcame the delays and difficulties of fog—at considerable capital and maintenance cost in signalling equipment. Frost could, and did, still reduce journey speeds with electric trains to well below 20 m.p.h., and except in the most adverse conditions would not do worse than that with well-designed trucks and buses.

Mr F. P. Dath (Civil Engineer, Central Electricity Authority) thought that the discussion had proceeded along the lines generally expected and it would seem that the scheme could be either condemned or upheld on a few of the salient points raised. In the first place, to those speakers who had mentioned the possibilities and the potentialities of another war it could be argued that there would quite plainly and definitely be another war, the magnitude of which would be predictable and so great that it would not matter anyway whether the nation was dependent upon home-produced electricity or upon foreign oils and rubber. Experience of previous wars showed that that factor alone would be sufficient to condemn the scheme for the very simple reason that the merchant navy, which was always strained to the uttermost at such times, would not want the

additional hazard of supplying fuel for transport which could otherwise be supplied with home-produced electricity.

He felt sure that the Author was under no illusion regarding the extent of the opposition to his ideas but was also sure that there was much to support the proposals. After 35 years of regular travelling on the railways, Mr Dath had formed the opinion that it was not a case of the railways serving the public but one of condescendingly allowing the public to use their railways. Apart from being possessive they were cautious to the *n*th degree.

Too often, a change in methods suggested to an old-established organization evoked the reply " we have done it in a certain way for the past fifty years ". Whilst agreeing that a tried and tested method which had proved its worth should not be lightly pushed to one side, Mr Dath thought that that remark typified the general attitude towards drastic change. For example, such accidents as those caused when the off-side door of a crowded carriage was accidentally opened and ripped off by a train passing in the opposite direction would be eliminated if the planners were more amenable to stepping forward from 1830 and would build with sliding doors.

The density of passenger traffic had increased many-fold on some suburban lines over the past 30 years or so, and it was high time that inefficient and uneconomic methods and designs were replaced.

Serious trouble frequently required a drastic remedy and it might well be that the solution of the traffic problem lay in scrapping the railways and moving forward with modern ideas. There seemed no real reason why the present system of railways should not give way to a more efficient means of transport if one could be found. There were a number of instances which could be cited as parallels. The aeroplane had taken the place of the less efficient airship, and when the advantages had been appreciated little real objection had been raised. Mr Dath had wondered if sentiment did not play too big a part in the retention of the railways—whatever the reason, the price the nation and the public were paying was too high. He travelled each day to London on what was generally accepted as being one of the worst of all suburban lines and if, during the peak hours of travel, a fault or fog caused delay, the chaos was unbelievable. He was sure the passengers on that line would give whole-hearted support to their railway being motorized if it could be taken away from its present possessors.

Finally, how did the Author propose that the transition should be carried out on those lines with very dense traffic ?

Professor Hermann Bondi (Professor of Mathematics, King's College, London) observed that a more limited approach would overcome the objections raised against the Author's brilliant ideas. It was generally agreed that a number of motorways would have to be provided in spite of

their enormous estimated cost, in spite of their waste of land, and in spite of their inability to run into city centres. Could the permanent ways of British Railways be of any assistance in those matters ? Closed sections of railways were unlikely to run where roads were most needed. But could not some main lines be more useful as roads than as railways ? Surely it was not a law of nature that London had to be connected with the Midlands and the North by five main lines, some of them four-tracked for long stretches ? A concentration of rail traffic on fewer of them would not only be possible, but economically preferable.

A good road should consist of two carriageways, each containing two driving lanes (each 10 to 11 ft wide*) and a parking strip, not necessarily continuous, 8 ft wide. A twin-tracked railway line was therefore quite wide enough for *one* carriageway, though the parking strip would have to be dispensed with in tunnels and on bridges (as it was on American highways). Two more or less parallel railway lines could therefore make a motorway. The wide separation of the two carriageways, though inconvenient in some ways, would greatly aid night driving.

As a start, the Marylebone–Rugby–Sheffield line might be made into a northbound road, and the line Sheffield–Kettering–St Pancras into a southbound road. There were enough tracks to retain the London–Aylesbury suburban rail service on the one and the whole rail service on the other, for it was four-tracked south of Kettering, and ran north from there along several parallel twin-tracked routes. The cost of conversion, though no doubt large, would be far smaller than for the construction of a new motorway ; the road would run into the cities and would not waste any land.

Ultimately, Mr Bondi suggested, those railway lines that were, or were due to be, electrified (owing to their heavy traffic) should remain railways, but the others might all be considered for conversion into roads. Incidentally, rail diesel haulage relied on imported fuel as much as did road transport.

Mr W. P. Andrews (Roads Consultant to the Cement and Concrete Association) remarked that the Author had referred to the irregularity index of 35 in./mile obtained recently on a high-speed motor track. The present method of measuring the irregularity index revealed only small surface irregularities and did not indicate the presence of surface waviness. That waviness might be the result of bad rolling or might be developed in a flexible surfacing by traffic. It caused long-pitch variations in level which could give unpleasant riding qualities and be very uncomfortable for the driver.

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* Returning to Britain after many thousands of miles of motoring in the United States, Mr Bondi had been struck by the wasteful and unhelpful width of the lanes in England. A 10-ft lane was quite adequate, more than 11 ft width was positively dangerous in encouraging small cars to pass in one lane.

A second point was the permanence of a good surface giving good riding quality. It had been customary in Britain in the case of concrete roads to specify a maximum tolerance of ⅛ in. in 10 ft, and that somewhat stringent standard had been consistently obtained, especially on main roads. What was equally important was that it had been maintained throughout the life of the road, often up to 25 years. There were many examples of such roads leading from London to the coast. Equally good riding qualities could be obtained with other surfaces, but they might soon disappear if creeping of the surfacing occurred, and waviness or corrugations developed.

Those considerations were of the greatest importance in the roads visualized by the Author, in which the traffic flow should suffer the minimum of interruptions such as were caused by repairs, ironing-out, and resurfacing.

Mr F. W. Davey (Consulting Engineer in private practice) remarked that even if the Author's proposals were not adopted in their entirety they might usefully be considered as a basis for schemes to relieve congestion in large cities. The case of London was an outstanding example. A possible application was illustrated in Fig. 2.

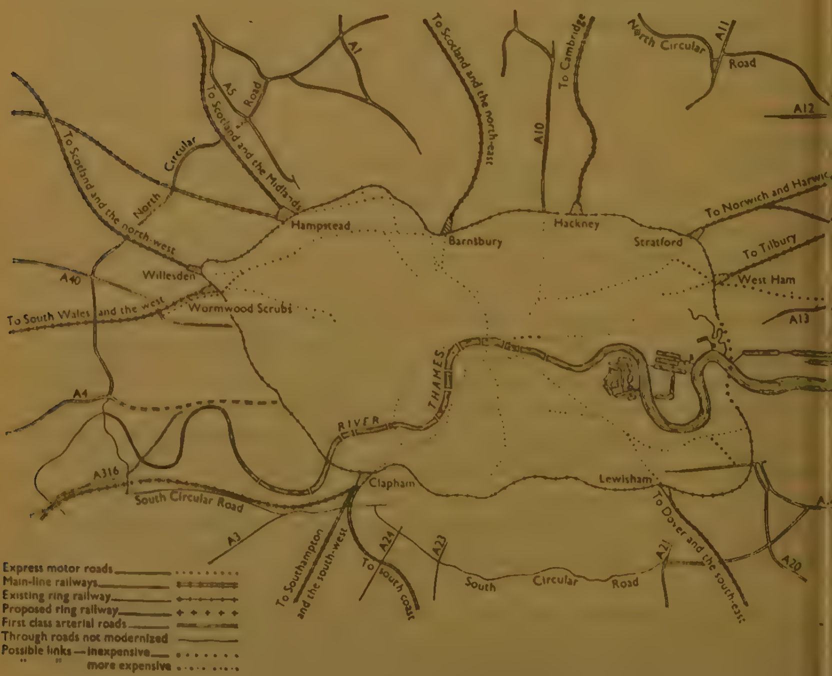

FIG. 2

There was in existence an almost complete ring of double-track railway. By means of works which, compared with the magnitude of the problem were of comparatively minor order, that ring could be made suitable for fast and frequent electric services. To be really efficient, the ring would have to be completed in the Greenwich–West Ham area by means of a tunnel under the Thames.

If now all main-line terminals were re-sited on that ring and all rail tracks within the ring were converted into motor roads the following considerations would apply.

1. All through rail traffic would transfer to the ring at the incoming terminal, and from the ring to the outgoing main line at the appropriate outgoing terminal. For example, passengers from Liverpool to Dover would transfer to the ring at the new Willesden terminal and from the ring to the Southern Region at the new Lewisham terminal. Luggage, etc., would similarly be dealt with expeditiously by modern installations.
2. Passengers and goods arriving at the new terminals for London would have the benefit of fast motorways to the central area. It was estimated that more than 90% of passengers arriving at existing terminals immediately transferred to some other form of conveyance.
3. There would be no road congestions at the existing terminal sites since road traffic to and from the new terminals would filter on and off the express roads *en route*.
4. In many cases the new express roads would fit conveniently into the existing scheme of arterial roads. In other cases links could be provided at relatively moderate cost. One major high level road link which might be considered would be between the existing terminals at Cannon Street and Fenchurch Street.
5. With the exception of Waterloo, all existing terminals were out of date and needed rebuilding. Moreover, existing main-line trains travelling from the ring to existing terminals seldom averaged more than 30 m.p.h., a speed which would be considerably exceeded by motor traffic on the new express roads.
6. In many cases the suggested new terminal sites would be adjacent to existing servicing sheds and tracks, thus assisting the operating departments to a considerable degree.
7. The project lent itself admirably to delegation of design work to many independent engineers and architects with the minimum of interference from a central authority, thus making for speed in execution. For that reason Mr Davey suggested that a period of the order of 10 years should suffice to bring

the plan to fruition and that in no other way could London's traffic problem be solved so soon.

Mr W. K. Taylor (First Principal Assistant Engineer, City Engineer and Surveyor's Department, Exeter) suggested that to justify their adoption the Author's proposals should:

(1) provide a highway system at least equivalent to recognized contemporary design standards for fast motorways;
(2) use the nation's fuel and manpower resources to the best advantage; and
(3) render services superior to those given by the railways using modern equipment and operational methods.

(1) *Highway system*

It did not appear that the converted road system would be entirely up to present standards for motorways since obtainable widths would be inadequate. Hutton[31] gave an overall width of from 88 ft to 93 ft having a median strip from 10 ft to 15 ft, dual 22-ft carriageways with 1-ft marginal strips and 15-ft verges. The American Association of State Highway Officials[32] recommended 12-ft traffic lanes where traffic density exceeded 200 v.p.h. per lane with 8-ft to 10-ft shoulders (except in mountainous terrain), and a median strip having minimum and desirable widths of 15 ft and 40 ft respectively in rural areas.

Adequate verges were essential for amenity, drainage, signs, and visibility[31] and also for storing snow cleared from the carriageway, as a "pull off" for brokendown or damaged vehicles and as a margin to accommodate men and materials when the road was being inspected, serviced, or repaired.

Regarding the suggestion that one 22-ft carriageway would suffice, Hutton[31] said that whilst it was possible that one might sometimes be constructed at first, ultimately dual carriageways must be provided for safety. Coburn[33] gave tabulated particulars of percentages of different types of accidents on roads without a speed limit (taken from "Ministry of Transport and Civil Aviation Road Accidents 1952"). That showed 17% as involving "two vehicles moving on same road in opposite directions." He stated that on dual carriageways collisions between vehicles travelling in opposite directions were eliminated and that the provision of a central reservation would be expected to reduce accidents by 17%, that expectation being in fact confirmed by accident rates given by Drake.[34]

In discussing motorway design, consideration must be given to:

(*a*) inadequate headroom and width in railway tunnels and bridges;
(*b*) ventilation required in tunnels;
(*c*) provision of flying or burrowing junctions; and
(*d*) that traffic control by signals would lead to increased journey times.

Thus it seemed that the railway tracks could not provide the required dimensions for motorways carrying traffic at minimum speeds of 60 m.p.h. and that there were other drawbacks which would be extremely expensive to overcome, even if at all possible.

(2) *Fuel and manpower*

(*a*) *Fuel.*—McBride [35] quoted Mr W. T. Faricy, President of the Association of American Railroads, as saying recently that to move 100,000 tons of freight from the Atlantic to the Pacific or vice versa, the requirements of diesel fuel would be 90 tank cars by rail, 250 by truck, and 2,700 by air, and, in terms of manpower, 3,500 man-days of train-crew time, 90,000 of truck-driver time, and 50,000 of plane-crew time. Whilst those figures might not be strictly comparable for Britain, they indicated great differences in requirements which needed serious consideration since oil fuel had to be imported.

Broadbent [36] stated that Mr J. Eccles, in his Inaugural Address as President of the Institution of Electrical Engineers in October 1954, had said that the accessible coal in Britain might be exhausted within about 200 years and that it was possible that the supply of oil might easily become critical within the lifetime of the present rising generation.

He gave the following reasons which made electric traction for railways more attractive than coal or oil from the viewpoint of energy conservation.

(i) The degree to which it could be integrated into the nation's power supply system.

(ii) The generator could be coupled to any source of energy—coal, oil or derivatives, hydro-electric, tidal, wind, solar, atomic, fuel cell, or any future development.

(iii) Possibilities of using waste heat.

(iv) Returning power to the system by regenerative braking.

It seemed desirable, therefore, that ultimately oil should be allocated to forms of transport other than railways, leaving the latter to use power sources available to them alone, thus conserving oil supplies.

Incidentally, railway vehicles did not run upon imported rubber.

(*b*) *Manpower.*—Against the estimate of 840 buses per hour as being required in Waterloo's rush hour, the timetable for August 1954 showed about 68 trains between 5 and 6 p.m., giving a very considerable saving in train crews. Furthermore, 500 trains carried 300,000 passengers on the Southern Region alone in London's morning rush-hour. That would require about 5,000 buses, about one half of the Author's figure of 10,300 vehicles. It must be remembered that multiple-unit trains could be increased and electric or diesel motive-power units coupled into twin or triple units and still only require one driver.

(3) *Service*

(*a*) *Weather.*—With modern colour light and automatic signalling, track circuiting, automatic train control, and centralized traffic control as provided in the British Transport Commission Plan,[37] and locomotive cab signals as used in America, the railways should be almost, if not entirely, unaffected by fog when road traffic was suffering the severest dislocation. Likewise, using de-icing measures, point heaters, etc., the railways should still be running when traffic was skidding to a standstill on ice-bound roads.

Those considerations would be of vital importance in war-time.

(*b*) *Services.*—Mr Taylor doubted whether the typical passenger service would work out as evenly throughout the day as suggested and it was quite certain that the large crowds at summer week-ends and other holiday times could not be so handled.

The use of car-hire service as the equivalent of first-class passenger travel, did not appear to compare favourably with long distance rail travel with its restaurant, toilet, and other facilities. For night rail travel sleeping cars were available which could be of the American roomette or bedroom type.

The British Transport Commission [37] aimed to achieve speeds of at least 100 m.p.h. where conditions permitted. With electric rail traction high speeds were easily obtainable, as for instance on express services in France and the United States. In the former country, an electric locomotive had reached 205·6 m.p.h. with a light test train, and the S.N.C.F. had running on their Western Region multiple-unit electric sets capable of accelerating to 62 m.p.h. in 35 sec and 93 m.p.h. in 93 sec [38] and of reaching a maximum speed on test of 103 m.p.h. It could be seen that with modern equipment railways could run services at average speeds well in excess of 60 m.p.h.

(*c*) *Safety.*—Mr Taylor did not consider 1952 to be a representative year for accident comparisons, since it included the Harrow and Wealdstone smash which produced the second largest number of deaths in a British rail accident.

(*d*) Finally, since the Author's Paper was written, the British Transport Commission's Plan [37] had been published and he would, no doubt, agree with Mr Taylor that when that had been fully implemented, the railway system and services would then differ considerably from those of 1952.

The Author, in reply, dealt with the points raised under subject headings rather than *seriatim*.

Traffic control

He wished first to assure Dr Glanville that he visualized a system of control fully as strict as that which yielded the very low accident figures of motorways abroad. All lanes would be marked with highly mounded catseyes, and the traffic code would include rules such as :—

(*a*) A strict keep-in-lane rule except at clearly marked places of transfer to an adjacent lane.
(*b*) Only uni-directional overtaking allowed on a three-lane roadway, the middle lane being allotted to one direction or the other, never both.
(*c*) No overtaking at all on two-lane stretches of roadway.
(*d*) No dawdling.
(*e*) No parking except in an authorized lay-by or shunt lane in a station, leaving the through lane clear.
(*f*) Forfeiture of special driving licence, for a period or permanently, on breaking the rules.

Single carriageways

In view of the considerable criticism of the Author's suggestion that double-track railway should be converted into single carriageway, instead of the more expensive dual construction, he felt it necessary to give his line of reasoning in that matter.

He had first regarded the indifferent roads on which he (and his critics) travelled daily with fair speed and safety. He had then considered the improved speed and safety that would be available on the permanent ways converted in the simplest manner without major earthwork. Finally, he had taken into account the further considerable gains resulting from the exclusion of undesirable traffic and the observance of a traffic code as given above.

To attempt to improve further upon the motoring conditions he daily experienced, by adding a second carriageway, seemed to the Author extravagant.

In the discussion, however, he had been confronted with a surprising postulate. Speakers had presumed the converted railways teeming with traffic, as if all the alternative existing roads had been closed down.

That was very flattering to the principle of railway conversion ; and if it happened it would probably render dual carriageways necessary, the Author agreed, for traffic volume was the accepted criterion for a second carriageway ; but mathematically it seemed impossible for a great many years to come.

Traffic censuses had shown that few stretches of the Class A trunk routes, beyond the confines of towns and cities, were habitually used by more than 6,000 vehicles a day. Only a proportion of those vehicles would be eligible for transfer to the converted railways as toll traffic. To them had to be added the former rail traffic ; but, as had been shown in the Paper, that would appear very sparse in its new form. Finally, it seemed to have been agreed that the bulk of the traffic would be carried satisfactorily on the 1,954 miles of roadway formed from triple or wider railway.

Accordingly on the stretches of roadway formed from double-track railway, which lay mainly beyond the confines of towns and cities, the

traffic flow would be very much too thin, the Author thought, to justify the expense of providing more than a single carriageway of basically three-lane width, intermittently of two-lane width, as described in the Paper. The capacity of that type of roadway would be more than twenty times the capacity of the double-track it had replaced. If it were overtaxed at any particular place the railway there clearly ought to have been triple originally, and it would no doubt have been scheduled for tripling under the railway modernization scheme.

Toll traffic

It appeared to have been accepted without discussion that the converted railways would be used as toll roads. The Author entirely agreed with that. The Paper had dealt mainly with passenger and freight public services only because the basic functions of British Railways would be fulfilled by those particular services.

Mr Goode had suggested restricting use of the system to commercial and public service vehicles only. But that would waste its capacity and limit the general benefit. The Author considered that as many drivers and vehicles as were fit to use the system should certainly be allowed to do so, paying toll. One aim should be to reduce congestion on the public roads as much as possible; another should be to keep the toll rate low, and that also demanded the maximum volume of toll traffic.

Journey speed

The Author had observed a tendency to read too much into his suggestion of 60 m.p.h. as the minimum acceptable journey speed, particularly on the part of Mr Taylor. That would, of course, not be a rigid minimum speed limit. The figure of 60 m.p.h. was only the Author's estimate of the average speed that would be achieved voluntarily by the traffic over the entire system, round the clock, and over the four seasons. No precise speed was essential to the argument for railway conversion: 40 m.p.h. might render it worth while. Initial experimental conversions would enable a closer estimate to be made, on which a re-evaluation of the scheme could be based. If it were found that the drivers slowed down excessively at the 24-ft bridges and tunnels, then the question of widening the bridges and tunnels should be taken up.

In bad weather every form of transport was subject to delay. The Author suggested that on that point, as on many others, there had been a tendency to think too much in terms of ordinary road traffic. The roadway traffic would not have to negotiate corners and gradients of the type that caused most of the trouble on public roads in icy weather. Prompt sanding and snow clearance could be arranged.

Safety

Three contributors to the discussion had impugned the Author's

selection of 1952 as the year instanced for railway casualties in Table 1. He had merely quoted the latest figures available to him when writing, and he had inadvertently given the provisional instead of the final figures for the August 1954 road casualties (23,784); the final figures were: killed 408; injured 23,357; total 23,765.

A straight comparison for the year 1953 had become available: roads 226,770; railways 25,475—a ratio of 9 to 1. The aggregate of human exposure to accident, howsoever measured, must be vastly greater on the roads than on railway property, certainly more than 9 times as great, in the Author's opinion. Furthermore three-quarters of the road casualties were slight, whereas a railway employee injured at work was not deemed a casualty unless absent for more than 3 days. Suicides and trespassers were not included in the railway figures.

Mr Osborne had distinguished between railway passengers and employees, and had been correct in stressing the relative safety of the passengers, for expert analysis had shown that "in undertaking a journey by public transport a passenger is as safe by road as by rail."[39]

Urban areas

In saying that the Author had proved the case for a modernized highway system Major Aldington implied a system akin to that planned in the Ministry of Transport under Mr Barnes, comprising new motorways that avoided or stopped short of towns and cities. But the Author disclaimed having made any such case; he would never have concerned himself greatly over those motorways—"pipes with their ends blocked" as Mr E. C. Gordon England had called them. The essence of railway conversion was that it provided high-speed routes where they were needed most, namely into and through urban and metropolitan areas.

Mr Seymer had appreciated that point, but his suggestion for putting the railways underground within such areas seemed impracticable financially: London Transport had stated that not even their proposed new tube railway, aligned to attract maximum traffic, could support the capital charges incurred in tunnelling. For similar reasons it must be doubtful whether the ideas of Lt-Col. Lovell for overhead construction were realistic. Perhaps those two speakers believed, as did many people, that Government subsidy was a legitimate principle in transport. That principle was certainly looming over the affairs of British Railways, but it might never achieve legitimacy in the eyes of the taxpayer. Instead the latter might come to regard British Railways as an affliction, which seemed to be how Mr Dath regarded them already.

It was important, the Author thought, that the public should appreciate the effects of railway conversion on themselves personally: perhaps they alone stood to gain from it at first; there seemed to be no "interest" that would profit from it initially, though all would gain in the long run. He therefore welcomed the limited schemes put forward by Professor Bondi

and Mr Davey: the people concerned could work out the effect on themselves; the London and Home Counties Traffic Advisory Committee might be interested to do that on behalf of Londoners in respect of Mr Davey's scheme. Moreover, as the Author fully realized, conversion would need to start in limited areas. He himself would not prejudice matters by suggesting which areas. The demand should come from the area, he felt. One such demand had materialized on the 1st November, 1954, when Sir David Robertson, Member of Parliament for Caithness and Sutherland, appealed in Parliament for the conversion of the line from Inverness to Wick. That line would provide perfect rural experience, but more would be learnt from urban areas.

Vehicle milage

Mr Ratter had been depreciatory of an annual vehicle milage of 150,000 because of the resulting £600 tire bill. The Author replied upholding that milage because of its effect on another item in the running costs of a vehicle.

Any vehicle had a fixed life which would be expressed in miles: a bus for instance commonly had a life of 500,000 miles in city service. If such a bus had forty-eight seats, with fares 1*d* per mile and a load factor of 50%, it could bring in at the very most, throughout its entire existence, a sum of £50,000.

In a city the bus would run approximately 33,300 miles annually and last for 15 years. Over this period its crew (5½ persons gross) would have to be paid say £2,500 a year, a total of £37,500, which at once lowered the ceiling of earnings from £50,000 to £12,500.

Were that bus given roads on which it could run 150,000 miles a year it would demand only 3⅓ years' work of its crew in accomplishing its £50,000 mission, and £41,666 instead of £12,500 would remain available to meet the other costs incurred in travelling the 500,000 miles.

That seemed just a typical instance of the known advantage in running machinery at a fast pace in a high-wage economy. It revealed the unimportance of £600 tire bills, and also of annual depreciation charges of about £1,000 per vehicle, once journey speed had been increased from 11 m.p.h. (London traffic) to 60 m.p.h.

In any event, at the present rate of technical progress, the Author submitted, there was much to be said for a system that enabled vehicles to be replaced every 3 or 4 years by new vehicles of greater efficiency. And 150,000 miles a year was not a lot. Motor coaches already ran 10,000 miles a month on the Scotland–London road service. Freight vehicles could be expected to achieve more running hours than passenger vehicles: a lorry in round-the-clock operation on say a 60-mile coal run between pit and power station, averaging no more than eight round trips a day, would cover 350,000 miles in one year. If it were a 20-tonner and the freight charge were 1½*d* per ton-mile, even though it always did the return journey

empty, it would still earn £60 a day gross—£21,900 a year. Altogether the Author felt he had been moderate in instancing in the Paper a vehicle that covered no more than 150,000 miles a year.

Number of vehicles

Mr Blee had indicated that the number of vehicles required might approach 500,000. The Author had been disappointed to glean nothing more substantial than indications from Mr Blee, but himself admitted having left that particular subject somewhat in the air; Lt-Col. Cartwright-Taylor had been able to interpret him satisfactorily.

The Author had, however, estimated on p. 738 that the number of vehicles might eventually reach 164,800 (41,200 × 4). "Nearer half-a-million" could therefore be put at 332,401. If that number of vehicles averaged 150,000 miles annually they would equal British Railways' 1952 output of passenger- and ton-miles when their load factor reached 3%, i.e., 40-seater buses carrying 1·2 passenger and 20-ton lorries laden with 12 cwt.

In contrast the Author had presumed a high standard of managerial efficiency, and his estimate of 164,800 vehicles had allowed for the traffic having quadrupled; his extrapolation had embraced hire cars and other light vehicles in public service. He suggested that Mr Blee's indication of "nearer half-a-million vehicles" could not be accepted outright, though it was by no means formidable in relation to the 6 million vehicles already in Britain, or to the British motor industry's annual output of more than 1 million vehicles.

Peak hours

The particular problem of deploying the passenger vehicles correctly during rush hours had been covered by Mr Blee in his remark that the demand in the Southern Region would leave none for Manchester. Mr Taylor had been more specific and had allotted the Southern Region 5,000 buses for the morning rush of 300,000 passengers. But Mr Taylor had not taken into account the fact that the average commuting distance was of the order of 14 miles. Over that distance a bus would take 40 minutes for the round trip and would therefore complete three journeys into London during the normal 1½-hour rush: only 1,666 buses might be required.

The Author agreed with Mr Taylor in disregarding standing room.

Manpower

On the subject of manpower Mr Taylor had quoted a railwayman who sought to leave an impression that 3,500 railwaymen were worth 90,000 lorrymen, and Mr Blee had invited consideration of the subject in relation to the staff employed in British Railways.

That had prompted the Author to point out that, roundly, British Railways employed 600,000 people in order to run daily 40,000 trains grossing 1 million train-miles. By simple proportion: 15 employees

produced daily no more than 1 train which accomplished one 25-mile run. Assessing the duration of that average train-run at 1½ hour, and the average employee's working day throughout the year at 6 hours, the Author deduced that British Railways' average train had to earn, in 1½ hour, sufficient to cover the wages of 15 people for 6 hours. The train was in effect carrying a " crew " of 60, though only 3 might be visible.

On the other hand a bus commonly necessitated 5½ employees and spent appreciably more than 6 hours in operation daily : its " crew " was therefore less than 5½ net—perhaps 4, compared with the train's 60. That disparity was offset to only a limited extent by the extra size of the train. Significantly the average takings in 1952 of a British Railways' passenger train and of a London bus *per diem* were approximately equal at about £13.

Mr Taylor had also pointed out that 68 trains ex-Waterloo would be replaced by 840 buses. By the Author's reckoning the manpower backing of the 68 trains would be 4,080. And if the buses were operating under city conditions their backing would amount to perhaps 3,360. But the buses would be operating under very different conditions : for instance they would not require conductors, and their " ground staff " and many of their overheads would be charged against toll receipts, not against bus takings. The inference was that a minority of the 600,000 employees would be directly engaged in passenger and freight public services : the salaries, wages, and pensions of the majority would derive, appropriately enough, from toll traffic.

Speed, in relation to other factors

The Author regretted he could not share Dr Daniel's interest in passenger train timings. To the Author's way of thinking the paramount factor in public transport was convenience, and the chief element in that was frequency. He had been disappointed that in the discussion the need for frequent services had been mentioned only once—by Mr Davey in respect of his ring main.

An expert evaluation of the factors that weighted with the public had placed them in the order : comfort, frequency, cost, time.[40]

The Author visualized a long-distance bus on the converted railways giving passengers all the comfort of an air liner without the noise, earache, bumps, and air sickness.

With regard to cost the Author had been particularly interested to note that his estimated running costs had been criticized by Mr Bond only in respect of the item 3·6*d* per mile for fuel, lubricant, and tires. The Author had been influenced by figures from a motorway in the United States, but did not wish to dispute the criticism. It would have been noted that his ½*d* fare allowed an overall margin of 108%, to cover criticism of costs and load factor ; he had refrained from claiming a fare of ¼*d* per mile.

Although speed might be only the fourth factor from the passenger's viewpoint, it was a vital factor in reducing the costs of operation, and it

made a very interesting study. The Author expressed a hope that Dr Daniel would include road speed in his researches.

Transit time

Dr Glanville had raised the point that the use of special vehicles that could not quit the converted railways would create trans-shipment difficulties. In the Paper the use of trailers had been suggested in partial anticipation of that problem ; but the Author admitted he had been over-imbued with a desire—very understandable in 1955—to evade the taxation and legislation that assailed any vehicle the moment it was driven on to a public road. He agreed that in practice it would often be best to use conventional vehicles and so compete on equal terms with toll traffic.

Mr Goode in his opening sentences had dwelt on the advantages of door-to-door transport and had shown how they could be reaped through railway conversion. They could be summed up as a saving in " transit time," and perhaps transit time was the truest yardstick to apply in transport matters.

The yardstick used by Mr Blee in comparing rail traffic with road traffic had been ton-miles : 22,000 million by rail, 7,000 to 8,000 million by road. Mr W. Andrews, Chairman of the Royal Automobile Club, writing in the *Sunday Times* on the 19th June, 1955 had used plain tons : roads 72%, rail 24%, coastal shipping 4%. In the Paper a financial yardstick had been used : roads £1,700 million, rail £500 million. No doubt all those comparisons were questionable, and the Author suggested that what was required in order to survey the national transport problem was a new analysis taking into account transit time.

In support of transit time as a basis for analysing transport problems the Author quoted the British Transport Commission : " a high proportion of the costs of railway operation is related to time rather than distance." [41] That principle was not novel : it underlay the development of jet air liners. A stage seemed to have been reached in transport affairs when time mattered more than distance : when the lowest-priced freight (which could not afford high-cost transport) ought to be conveyed fastest. If that were correct a highly relevant fact in any investigation of railway conversion would be that on British Railways the average haul for coal was only 56 miles, and for minerals 76 miles, and therefore lorries engaged on that important class of traffic would be able after conversion to *deliver* their loads successively sooner than railway wagons could at present be marshalled into train, let alone start their journey.

Brigadier Parkman favoured the train as a " larger unit," and elsewhere there had been postulated " the great natural advantages of railways as bulk transporters." [41] But, in the Author's view, bulk transportation was incompatible with the economics of an age in which the old saying " time is money " had gained force. The ideal form of transportation for the convenience of the client or customer had always been a flow, or movement in

small units; that type of movement had perhaps become essential to the financial viability of the transporting agency, especially in a small country such as Britain.

Cost of conversion

The Author was confident of not being alone in feeling that Mr Goode's contribution on the cost of conversion had added greatly to the value of the discussion.

Mr Goode had arrived at a figure of £1,000 million. He had remarked that that figure would not be exceeded at the outside, but the Author felt it might still give a wrong impression. It represented approximately £3 per sq. yd overall.

The blacktopped portion of the Lindley track had cost only £2 per sq. yd; it had been constructed on virgin land, and the stone had had to be hauled about 40 miles. The Author wondered whether Mr Goode had allowed sufficiently for the incorporation of railway ballast in the road structure, and for the use of the out-size pavers that might be specially developed for such highly repetitive work.

There were approximately 8,000 stations (including 2,200 for freight only) to be considered in addition to the paving; but at those stations people would no longer need to congregate in mass: they would enter their bus at once or after only a short wait. The stations could therefore be simpler, and very little more than platform removal would be required at the minor stations comprising the majority of the 8,000.

The Author would have included lighting at £4,000 per mile along the 12,300 miles of former double and wider track, but even so would not have put the figure above £600 million.

Fuel

Mr Warder had stated that additional railway electrification could not absorb more than 2% of the concurrent *increase* in the national generating capacity. The Author hoped that that statement would help to bring the fuel problem into perspective; in relation to the total output of electricity the demands of transport must always remain unimportant.

There was a common tendency, the Author thought, to exaggerate the fuel problem, perhaps because of British Railways' annual consumption of 13 million tons of coal. That consumption was attributable mainly to the limited efficiency of steam locomotives, and to the deadweight of trains, which was seldom less than 1 ton per passenger.

The minimum essential power for the movement of a passenger or a load was trivial, and that was a field in which great advances could be expected, motive units becoming more efficient and all vehicles lighter, with resulting economy in fuel. Appreciable advances in that field could hardly occur in railway locomotion because of the fixed power-weight ratio of locomotives; but tremendous advances could be expected as soon as Britain's

mechanical engineers started designing special vehicles for special roads. The solid-fuel gas-turbine might eventually reduce Britain's dependence on imported fuel; finally the atomic vehicle might materialize.

The future

There had been a robust warning from Mr Harding on the need to look ahead, and it was on that note the Author wished to end.

A vast increase in the ownership of vehicles by individual people and businesses was certain to occur. Meanwhile, as had been mentioned by Major Carter, the overall volume of freight might diminish rather than increase. Under those circumstances what was to be the future of British Railways? Already the volume of traffic accruing to them seemed to have fallen below the critical level for viability. Their forlorn palliative, comprising a reduction in the services they offered to the public, was to be adopted as a main feature of their proposed modernization; it would enable their remaining services to be improved and to be run at lower charges than would otherwise prevail.

Thus contraction seemed to be the keynote of British Railways' plans for the future; and the growth of commercial and private motoring, fostered by a modest improvement in the public road system, threatened to enforce a greater degree of contraction than had been planned.

The Author submitted that the straightforward civil engineering operation of turning the railways into roads seemed to offer British Railways expansion in the place of contraction. It would increase the traffic-carrying capacity of the permanent ways far beyond their present capacity as railways, and it would enable them to be used by the chosen vehicles of this generation and doubtless of future generations. In the opinion of the Author there might be a wonderful future for British Railways as the proprietors of truly arterial roads that could play a vital part, directly or indirectly, in the daily lives of every man, woman, and child in Britain.

Finally, the Author endorsed gratefully a recommendation made by several contributors to the discussion; namely that the subject, which the Institution had graciously invited him to present before them, should be further examined.

Correspondence on the foregoing Paper is now closed.—SEC.

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ORDINARY MEETING

24 May, 1955

DAVID MOWAT WATSON, B.Sc., President, in the Chair

The Council reported that they had recently transferred to the class of

Members

Bruce, John Fraser, B.E. (*New Zealand*).
Butland, Arthur Norman, O.B.E., B.A., B.Sc.(Eng.) (*London*).
Cassel, Frederick Leon.
Dalal, Shantilal Bhagwandas, B.E. (*Bombay*).
Daldy, Alfred Frederick.
Ferrie, Allan, B.Sc. (*Glasgow*).
Forsyth, John Macdonald Gordon, B.Sc.(Eng.) (*London*).
Hall, Harry Frederick, B.Sc.(Eng.) (*London*).
Hutchinson, Ian Alastair, B.Sc. (*Glasgow*).
Jepson, Fred, O.B.E.
Lacey, Robert.
MacLeod, James William, B.Sc. (*Aberdeen*).
O'Riordan, Jeremiah Augustine, M.A., B.E. (*National*).
Powell, Alan Edgar, B.Sc.(Eng.) (*London*).
Sarginson, Richard Russell, M.Eng. (*Liverpool*).
Serpell, Charles Anthony, B.Eng. (*Sheffield*).
Shahani, Chetanram Mangharam, B.Sc. (*Edinburgh*).
Tull, Donald William.
Vaughan-Lee, Gerald Hanning, O.B.E.
Watson, William Alexander.
Young, William Chuter.

and had admitted as

Graduates

Allinson, Maurice Graham, B.Sc. (*Bristol*), Stud.I.C.E.
Barden, Laing, B.Sc. (*Durham*).
Bramson, Michael Joseph, B.Sc. (*Birmingham*), Stud.I.C.E.
Burnside, Frederick Gordon, B.Sc. (*Durham*), Stud.I.C.E.
Burtt, Christopher David, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
Cox, Graham Clive, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Cox, William Ramage, B.Sc. (*Glasgow*), Stud.I.C.E.
Criticos, Demetre Mazarakis, B.Sc. (Eng.) (*London*), Stud.I.C.E.
Day, Geoffrey Francis, B.Sc. (*Nottingham*).
Dearden, Arthur Kay, B.Sc.Tech. (*Manchester*).
Essex, Michael John, B.Sc. (*Birmingham*), Stud.I.C.E.
Fernando, Mervyn Clair Elmo, B.Sc. (Eng.)(*London*), Stud.I.C.E.
Frewin, Thomas Frederick, Stud.I.C.E.
Guild, Allan Cook Bruce, B.Sc. (*Glasgow*), Stud.I.C.E.
Handcock, Michael George, M.Sc. (Eng.) (*London*), Stud.I.C.E.
Hansson, Christian Thaulow, Stud. I.C.E.
Hazzard, Anthony Oliver, B.Sc. (*Leeds*), Stud.I.C.E.
Hill, Thomas, Stud.I.C.E.
Horn, David Thomas, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Hornby, Graham, Stud.I.C.E.
Horne, Gerald Herbert, B.Sc.(Eng.) (*London*).
Iswariah, Lakshman Holm, B.Sc. (Eng.) (*London*), Stud.I.C.E.
Jones, Graham Insall, B.Sc. (*Wales*).
Longley, Norman Lewis, B.Sc. (*Wales*).
Munsch, Anthony Mark, Stud.I.C.E.
Nallaiah, Joseph Thurairatnam, B.Sc. (*Ceylon*), Stud.I.C.E.
Neads, Murray George, Stud.I.C.E.

Parkinson, Alan Sydney, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Pile, Kenneth Charles, B.E. (*Adelaide*).
Ronan, Stephen Ralph, B.A., B.A.I. (*Dublin*).
Roper, Colin Eric, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Rutter, Peter Arthur, Stud.I.C.E.
Sellier, Robert Hugh, B.Sc. (*Durham*).
Shaya, Morris Fadhil, B.Sc. (*Durham*).
Simpson, George Richard, B.Sc.(Eng.) (*London*).
Streeter, Tony William.
Urbanowicz, Andrzej, B.Sc.(Eng.) (*London*).
West, John Douglas, Stud.I.C.E.
Whittle, Geoffrey Farrow, B.Sc. Tech. (*Manchester*), Stud.I.C.E.
Wroth, Charles Peter, B.A. (*Cantab.*).
Yusuff, Muhammad, B.Sc. (*Wales*).
Zurel, Michael, B.Sc. (*Witwatersrand*).

and had admitted as

Students

Atkinson, Robert James.
Austen, Richard John.
Bailey, John Douglas.
Bowyer, Graham John.
Chian Shih Fang.
Clark, John Finlay.
Cochrane, Graham Hugh.
Davies, Gwynne.
Eastwood, Terence Joseph.
Endean, Michael George Devereux.
Goord, Derrell Lawrence.
Hancock, Raymond Brian.
Ho Kwok Yu.
Howard, Dennis Graham.
Howitt, Kenneth.
Jamieson, David.
Jermy, Barrie Stuart.
Jones, Edwin Peter.
Larkins, Alan.
Lawson, Peter.
Lucas, Peter Southgate.
McCarthy, Donald Morton.
McNaughton, Norman.
MacPherson, James Lauder.
Mann, Geoffrey Edward.
Modgill, Ravinandan Kumar.
Moglia, John Graham.
Morgan, Idris David.
Mtimkulu, Wilfred Richard Shadrack.
Paterson, William Neil.
Pearson, Richard Gilbert.
Price, Colin James.
Prosser, Rodney Stuart.
Ramokoka, Joseph Mokoke.
Skinner, Angus Evan.
Sketch, Anthony Edward.
Sladdin, John Peter.
Urquhart, William Ross Frazer.
Valentine, James Alexander.
Waddell, James.
Williams, Joseph Litsebe.
Woolfall, George Derek.

JAMES FORREST LECTURE, 1955

The President reminded Members that the James Forrest Lectures had been established in 1891 at the wish of James Forrest, who had been Secretary of the Institution from 1859 to 1896 and Honorary Secretary until his death in 1917. The original endowment had been the balance of a sum of money subscribed by Members of the Institution for engraving the portrait of Mr Forrest; to that endowment Mr Forrest had added a similar sum by bequest to the Institution, in order to establish a series of Lectures. He had also bequeathed to the Institution a number of pieces of presentation silver, of which he had been the recipient during his Secretaryship. This evening marked the sixty-first Lecture of the series, which would be delivered by Sir John Cockcroft, K.C.B., C.B.E., M.I.Mech.E.(Hon.), M.I.E.E., Pres. Inst. P., F.R.S. It would, said the President, be presumptuous on his part if he were to give any introduction to Sir John, who was well known to all present, but he wished to give a reminder, by reading a biographical note which had been put into his hand, that Sir John was no idle meddler in this subject.

Sir John Cockcroft was born in 1897 and educated at Manchester University and St John's College, Cambridge. He was Jacksonian Professor of Natural Philosophy at Cambridge, 1939–1946. He was Chief Superintendent, Air Defence Research and Development Establishment, Ministry of Supply, 1941–44; Director, Atomic Energy Division, National Research Council of Canada, 1944–46; Chairman, Defence Research Policy Committee, and Scientific Adviser, Ministry of Defence, 1952–54; Director, Atomic Energy Research Establishment since 1946, and a member of the Executive of the United Kingdom Atomic Energy Authority.

Was it necessary for him to add anything to that? He now had very great pleasure in asking Sir John Cockcroft to deliver his Lecture on "The Development of Nuclear Power."

Sir John Cockcroft then delivered the following Lecture.

THE DEVELOPMENT OF NUCLEAR POWER

by

Sir John Cockcroft, K.C.B., C.B.E., M.I.Mech.E.(Hon.), M.I.E.E., Pres. Inst. P., F.R.S.

The British Government, three months ago, published a White Paper describing its plans for the development of nuclear power in this country; it is a boldly conceived plan by which we look forward to supplying a progressively increasing share of our energy requirements from the energy of the atomic nucleus, starting with the feeding of over 50,000 kilowatts to

the National Grid in less than two years' time and looking forward to doing the work of 40 million tons of coal a year by the 1970s.

These developments have been based on discoveries in science made during the past 50 years and particularly on the work of Rutherford and his school, and since I was privileged to be a member of this school for 15 years I will first look back at these eventful years. The early years of the century saw Rutherford at McGill University experimenting with Soddy on the natural transformation of radium and thorium and their daughter products. These elements were found to throw out a continuous stream of high-speed particles—helium atoms and electrons—carrying a great deal of kinetic energy. In Rutherford's classical treatise on radioactivity published in 1904, he said that there was reason to believe that an enormous store of latent energy was resident in the atoms of radioactive elements—energy which was derived from the internal energy of atoms. Rutherford went on to say that if it were ever possible to control at will the rate of disintegration of the radio elements an enormous amount of energy could be obtained from a small quantity of matter.

Through the next decade the source of this energy became a little clearer; Rutherford found that it resided in the atomic nucleus—the minute positively charged core of the atom from which the high-speed alpha particles were ejected. A little later he discovered how to disrupt nuclei of light elements by using his alpha particles as transmuting bullets. And in these processes of transmutation, energy on a microscopic scale was released.

The scale of atomic transmutation was greatly increased in 1932 when we were able to use electrically accelerated hydrogen nuclei to transmute atoms of lithium and other light elements. We discovered what are now known as fusion reactions, but even so we seemed far from achieving a usable release of energy from the nucleus. However, in that same *annus mirabilis* of nuclear physics, another key to the release of nuclear energy was found when Chadwick discovered that neutrons were ejected from nuclei in the transmutations and neutrons were soon found to be very powerful projectiles for producing further transmutations. Fermi found that they could transmute uranium nuclei and produce a number of new radioactive elements. The chemists Hahn and Strassman found that these elements behaved like atoms in the middle of the periodic table—such as cerium and lanthanum—and they came to the conclusion that the heavy nucleus must be splitting into two heavy radioactive nuclei. This was rapidly confirmed by the physicists who showed that the energy released was very high—ten times higher than in any previous known transmutation.

From this time to Fermi's achievement of the first nuclear chain reaction in a graphite pile took four years.

In this country the French physicists, Halban and Kowarski, worked in Cambridge with the few British physicists available from the war effort to study the possibility of a controlled chain reaction in a heavy-water pile.

But we had only 180 litres of heavy water and it was not until we joined forces with Canada and obtained heavy water from the Traill plant and uranium metal from the United States that the joint Canadian–U.K. project obtained experience in building and operating two heavy-water piles. The first was the ZEEP—a zero-energy experimental pile. It was built to operate at a very low power so that the effect of changes in its design parameters could be studied. This has since turned out to be an essential step in designing any new reactor, for optimum parameters cannot be determined accurately by calculation and must be checked by the assembly of a zero-energy system.

The Canadian project followed this by building a high-power water-cooled heavy-water reactor to serve as a development tool. In this reactor an average of about 4 mW of heat are generated in each ton of uranium metal and as a result very intense neutron and gamma radiation is produced in the core. This enables the reactor to be used to test components of future reactors—the high neutron flux enabling the testing time to be short.

All this technical knowledge flowed back from Canada to Britain in 1946, when many of the British team returned to found the Harwell Research Establishment. We did not have supplies of heavy water available and so we built ourselves two graphite piles. The first was a low-power reactor—GLEEP—now used for testing the nuclear properties of reactor materials—such as graphite and uranium metal and also for measuring nuclear constants. This is another essential tool of atomic energy. The second reactor—BEPO—which develops 8 mW of heat is a research and development tool like the Canadian reactor. It provides a very large amount of experimental space for testing reactor components. It is also a major alchemical factory, producing a large part of the radio isotopes used in the world, and provides physicists with beams of neutrons which emerge from channels in the shield and travel down evacuated tubes to experimental apparatus. At the present time more than fifty experiments are proceeding in BEPO and even so we do not have space enough and radiations intense enough, so we are now building two more powerful research and testing reactors.

The development of nuclear power

The first step in designing a nuclear-power reactor is to settle the main parameters of the reacting core. The designer of a so-called thermal reactor has a choice of four moderating materials—ordinary water, heavy water, graphite, and beryllia or beryllium. The nuclear fuel for an ordinary water-moderated reactor must be " enriched " in U235, i.e., the proportion of U235 in the fuel must be somewhat greater than normal. For the other moderators natural uranium can be used. The heat-transfer fluid is largely determined by the moderator used. Water moderated reactors naturally

use water as the heat-transfer fluid. Graphite reactors can use either compressed gas, water, or a liquid metal. The heat transfer fluid in turn determines the sheathing material which must be used to contain the uranium metal, since the sheath and heat-transfer fluid must be compatible at high temperatures and in the presence of intense radiation. Water-moderated reactors can use either sheaths of stainless steel or an alloy of zirconium. Gas-cooled reactors can use alloys of magnesium, zirconium, or beryllium.

Table 1 shows the range of choice open to designers. In this country we decided in 1952 to adopt the gas-cooled graphite-moderated nuclear-power station for the first stage of our nuclear-power development, since this was a natural development of our experience with BEPO and the Windscale graphite reactors, and it has the great advantage of being able to use natural uranium fuel or only slightly enriched fuel.

TABLE 1.—TYPES OF THERMAL REACTORS

Moderator	Ordinary water	Heavy water	Graphite		Beryllium or beryllia
Coolant	Water	Water	Gas	Liquid sodium	Liquid sodium
Sheath	Zirconium or stainless steel	Zirconium or stainless steel	Magnesium alloy Zirconium alloy Beryllium alloy	Zirconium	

Having tentatively fixed the moderator, fuel, and sheathing material, the next step is to determine the best values of lattice pitch, fuel-rod diameter, and sheathing thickness to give the minimum size of reacting core whilst providing for an excess of neutrons to be available in the chain reaction. This is decided by the reactor physicist, who builds a sub-critical reactor to determine the neutron balance sheet for a particular set of parameters of the reacting core. These are varied in a succession of experiments until the best set of parameters is found.

An increase in the core size reduces the proportions of neutrons escaping. A decrease in the lattice pitch increases the number of neutrons absorbed to make plutonium. Increases in fuel-rod diameter increase the amount of fast fission and change the amount of plutonium produced. An increase in fuel-rod-sheath thickness absorbs more neutrons. A typical neutron balance sheet is shown in Table 2.

The reactor physicist has to see that the design provides for a surplus of neutrons, not only when the reactor is cold and operating at zero power but when it is operating at full power and temperature. An increase of

TABLE 2.—APPROXIMATE NEUTRON BALANCE SHEET FOR GRAPHITE PILE

Neutrons per fission of U235	2·5
Fast fission neutrons from U238	0·06
Total neutrons from fission	2·56
Absorbed in U235 to produce further fission	1·00
Absorbed in U235 to produce U236	0·2
Absorbed in U238 to produce plutonium	0·9
Absorbed in moderator	0·3
Absorbed in other materials	0·05
Escaping from core	0·09
Excess neutrons δk	0·02
	2·56

temperature usually absorbs more neutrons. When the chain reaction is proceeding fission products are formed which absorb neutrons. An important example is radio-xenon which decays fairly rapidly with a half life of 9 hours and turns into Caesium which does not absorb neutrons appreciably. So the xenon level builds up until the amount produced by fission equals the amount decaying. The neutron absorption or poisoning of the chain reaction thus increases with the power level until virtually all the poison is destroyed by neutrons before it can decay.

There are also longer-period changes in the neutron balance sheet arising from other fission products. Thus samarium is formed and this leads to a loss of neutrons or a fall in reactivity with time. There are changes also because the U235 is being destroyed and partially converted into plutonium. For a time this improves the neutron balance. The greater the conversion factor of U235 to plutonium the longer will this favourable balance persist in the life of a charge of nuclear fuel and the greater the amount of heat which can be extracted before the balance-sheet goes negative. So the reactor physicist aims at the greatest conversion factor possible.

Reactor physics experiments of this kind may easily take a year. Whilst this is going on, metallurgists develop fuel elements and their sheaths and test compatibility under irradiation by a very extensive and expensive series of experiments carried out under controlled conditions of temperature and radiation in an existing reactor such as the BEPO, the Windscale piles, or the Chalk River pile. A test loop for this purpose is a substantial engineering job and may cost £25,000 to £50,000. The time of test is shortened by using a high neutron flux reactor. We have been particularly fortunate in having access to the Canadian N.R.X. reactor for some of our work. One of our heavy-water test reactors now under construction will provide facilities for about eight such loops.

Radiation chemists have to study the interaction of reactor radiation with the heat-transfer fluid and moderator. Thus the reaction between graphite and CO_2 leading to formation of CO is found to increase rapidly

with radiation intensity, and could lead to mass transfer of carbon. So a large scale test loop operates in BEPO to study this.

These are only a few examples of the development projects which go towards a reactor design and we can identify up to fifty such projects in the development stage of a reactor.

These projects are of course all servants of the engineering design team who are themselves engaged in design studies. They have to solve the problems of arrangement and construction of the core and the containing pressure-shell. They have to provide for changing fuel elements and for detection of failures of fuel elements. They collaborate with the boiler makers and the turbo-generator manufacturers to weave all into an integrated design.

The design study of the first graphite-moderated power reactor was carried through by Mr B. L. Goodlet and Mr R. V. Moore in 1952, following some earlier work carried out by Harwell, the Industrial Group of the Atomic Energy Authority and Messrs C. A. Parsons. On the basis of Goodlet and Moore's report it was decided that the Industrial Group of the Atomic Energy Authority should design and build a nuclear power station of this kind.

The Calder Hall nuclear power station

A brief account of this first British nuclear power station was given by Sir Christopher Hinton in his James Clayton Lecture [1] to the Institution of Mechanical Engineers. The power station consists of two nuclear reactors. Fig. 1 shows the general arrangement of one reactor. It consists of a graphite core enclosed in a pressure vessel of just less than 40 ft diameter. The core is built up from many thousands of accurately machined bricks of very pure graphite. Between the bricks are vertical channels in which sit uranium-metal rods sheathed in a light alloy. The chain reaction is controlled by vertical control rods which absorb neutrons when they are lowered into the core. Surrounding the pressure vessel is a so-called " biological shield " which absorbs any radiation leaving the core, and so makes it safe to work nearby. The chain reaction will be started by withdrawing the control rods and heat will be developed in the uranium metal. The heat will be transferred by circulating carbon dioxide under a pressure of 6–7 atmospheres to four steam generators situated symmetrically round the reactor. It is intended to operate the reactor so that the uranium-metal rods are at a temperature of about 400°C. This provisional temperature limit is set by the corrosion of the light alloy sheathing by the hot carbon dioxide and possibly by the distortion of the fuel elements. We have little doubt, however, that in time this temperature limit will be increased by the development of improved alloys. Fig. 2 shows the steam cycle which will

[1] " Nuclear Reactors and Power Production." Proc. Instn Mech. Engrs, vol. 168, (1955), p. 55.

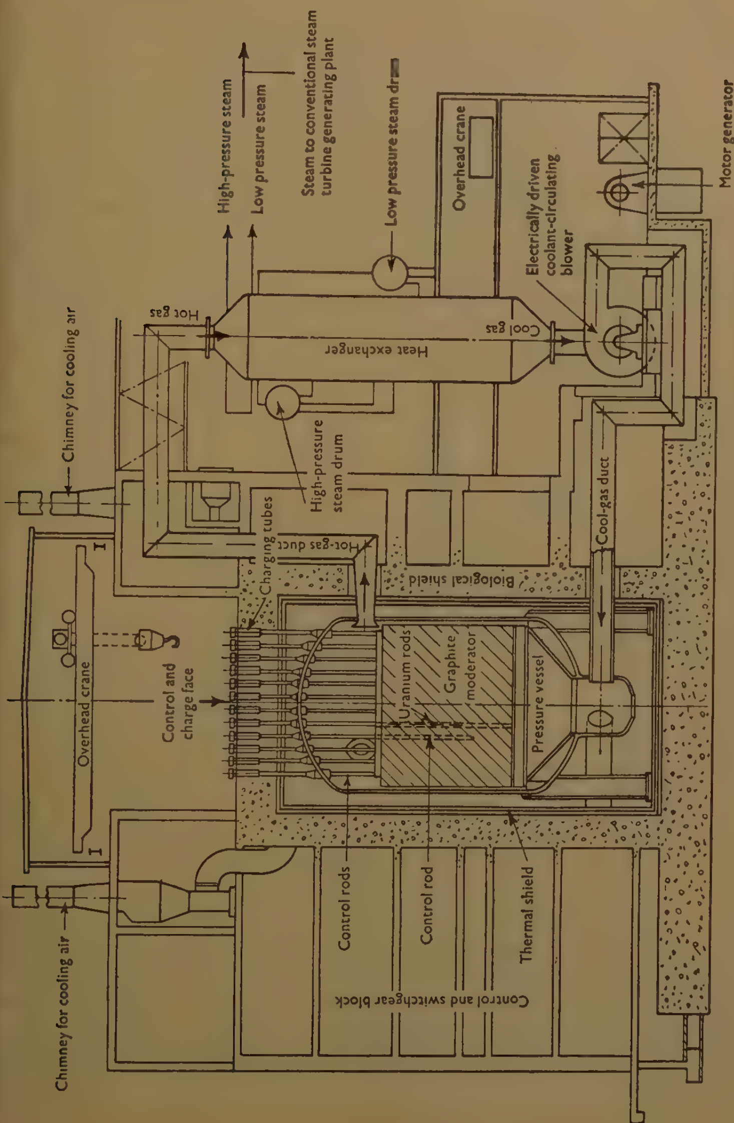


FIG. 1.—A GAS-COOLED POWER REACTOR
(Reproduced by permission of the United Kingdom Atomic Energy Authority)

be used. In future designs a thermodynamic efficiency of at least 25% should be achieved.

This first nuclear power station has been designed to fill a dual-purpose role. It will produce plutonium for military purposes and it will deliver more than 50 mW of electricity to the Grid.

This power station will be followed by the construction, starting about mid-1957, of two nuclear power stations for the Central Electricity Authority. Each of these will have two graphite-moderated reactors as the source of heat. They will be followed by ten further stations to be completed by 1964. These stations are to be designed by groups of industrial firms whose teams have been getting experience during the last 2 years at Harwell and at the Atomic Energy Authority Industrial Group.

The White Paper predicts that each of the power stations, comprising two reactors, should have a net output of electricity of 100–200 mW. The actual amount will depend on the details of the design adopted. Output can be increased by improvement of the heat transfer rate—by increasing

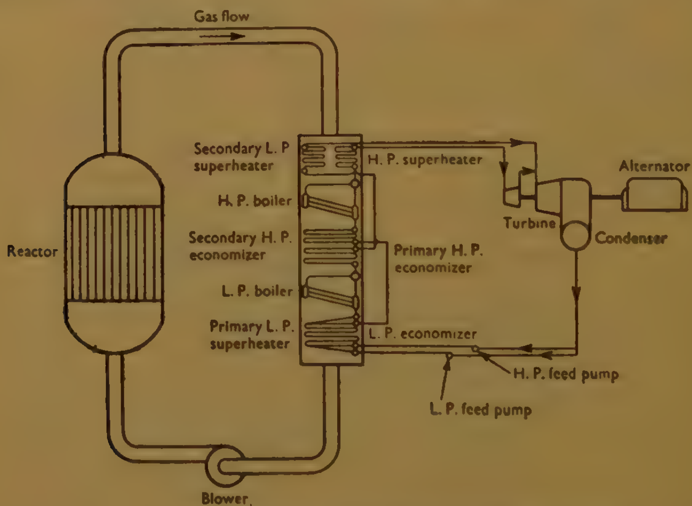


FIG. 2.—SIMPLE DOUBLE-PRESSURE STEAM CYCLE FOR USE WITH GAS-COOLED PILE

the pressure or by changing the heat transfer medium ; also by increasing the operating temperature. Capital cost per megawatt will be closely related to the increase of output achieved. The White Paper gives the capital cost of the Calder Hall pair of reactors as £15–20 million, so that if the median output of 150 mW is achieved the capital cost would be about £120 per mW.

The fuel cost for these reactors will depend on the amount of heat extracted per ton of uranium. This is determined by two main factors. The first is the nuclear balance of the reactor, which I have already discussed. Experiment shows that reactivity first decreases and then increases above its original figure and finally declines again. In operation, of course, these changes are compensated for by the position of the control rods. When all the spare reactivity is used up, the central part of the fuel

charge—which will have been most highly irradiated—must be changed. Reactivity is not, however, likely to be the limiting factor, since the life of the fuel elements will probably be limited by metallurgical imperfections. Whilst the chain reaction proceeds the U-metal rods are permeated by a flux of high-speed neutrons—about 10^{13} per sq. cm/sec. These fast neutrons displace atoms from their equilibrium position in the lattice. The high-speed heavy fission fragments are even more disruptive and produce localized stresses. There is also an accumulation of fission gases such as radio krypton and radio xenon which can build up considerable pressures. Added to this, uranium is a non-cubic metal subject to twinning and slipping. The result of all this can be to produce severe distortion of the U-metal rods—a distortion severe enough to split the alloy sheath, thus allowing radioactive products to escape into the heat-transfer gas.

Such failures may thus limit the heat extractable in the first cycle of use of fuel elements. Experience at Chalk River has shown that at low temperatures the heat equivalent of 3,000–4,000 mW-days/ton may be extracted. Our experience of high temperature operation is accumulating in the existing Windscale piles. We are at the same time carrying out metallurgical development to produce long-lived fuel elements and believe that by the time the first C.E.A. reactors are in operation we shall be able to extract the heat equivalent of 3,000 mW-days/ton. This would mean that we obtain from 1 ton of uranium the heat equivalent of 10,000 tons of coal of calorific value 12,000 B.Th.U./pound. With coal at £3 per ton this means that fuel costs would be one-half of coal-fuel costs if uranium fuel rods can be fabricated for £15,000 per ton.

In calculating fuel costs we must also take account of the initial capital investment in fuel and the fact that the spent uranium will contain a substantial amount of valuable fuel, plutonium. So the fuel rods will be sent to a chemical processing factory and the radioactive waste products which poison the chain reaction will be removed. The chemical plant may also separate the plutonium and it can be set aside as a valuable fuel for reactors of the future—stage 2 reactors—or as fuel for the breeder reactors which form stage 3.

Alternatively the mixture of depleted uranium and plutonium can be refabricated into fuel rods and sent back to the reactor for a second cycle. It seems likely that the fuel can be re-cycled several times in which case the initial cost of the uranium may be less important than the chemical processing costs.

It is early days to make accurate predictions of overall costs of nuclear power but the White Paper predicts that by taking a reasonable price for plutonium after the first cycle the cost of nuclear power for the first C.E.A. station should be about 0·6*d* per unit.

The operating characteristics of natural uranium nuclear power stations of the graphite type are by now reasonably well known. Fig. 3 shows the response of the Harwell BEPO reactor to a change in control-rod position.

It will be seen that there is a power transient and a temperature transient—a rise of temperature followed by a fall as increased temperature decreases reactivity. Reactors of this kind have therefore the valuable property of a negative temperature coefficient which makes for inherent safety. Start-up and control of the BEPO is now entirely automatic and after start-up

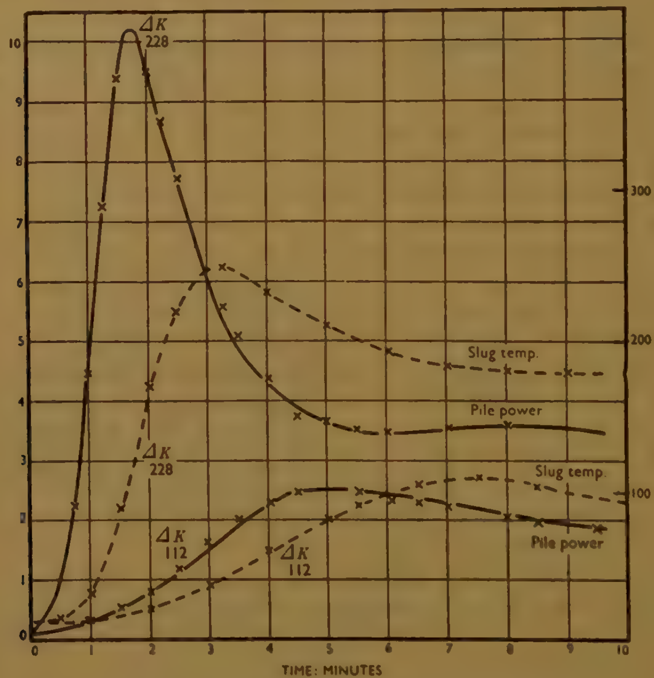


FIG. 3.—POWER AND TEMPERATURE TRANSIENTS

power levels are maintained constant to within one part in 1,000. Fig. 4 shows the growth of power under automatic start-up.

An important part of operational procedure is the detection of incipient failures in the sheaths of the U-metal rods. Failure may occur owing to pin-holes developing in the end seals or to distortion resulting from temperature cycling fracturing the can. When a crack or pin-hole develops, small quantities of fission products leak into the cooling gas and are at once detected by radioactive monitors. There is plenty of time to change the defective fuel elements before oxidation of the uranium sets in and produces serious contamination.

If no changes of fuel rods are necessitated by such failures a single charge of fuel may last 2 to 3 years.

Operators of graphite reactors must also watch the effects of neutron bombardment in producing changes in the properties of the graphite

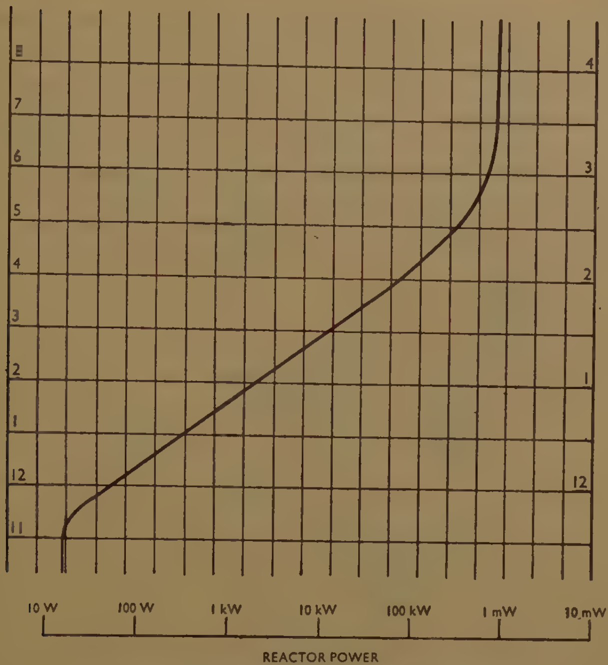


FIG. 4.—BEPO. GROWTH OF POWER UNDER AUTOMATIC START UP

caused by displacement of atoms in the lattice. Information is rapidly accumulating and will be described in future publications.

STAGE 2 OF THE U.K. NUCLEAR POWER PROGRAMME

The White Paper suggests that at some point in the programme, reactors of a new type will be introduced and that these may be of the water-moderated type. A reactor of this kind may use either heavy water or ordinary water as a moderator. If heavy water is used the moderator is expensive but the fuel can be natural uranium. If ordinary water is used the fuel must be slightly enriched in Uranium 235, so initial fuel costs will be higher.

The Canadian atomic energy project is building a pilot heavy-water power station with an electrical output of 20 mW. The United States is building a pressurized (light) water reactor for their first commercial nuclear power station. It is being built by the Westinghouse Company for the Daquesne Power Company and will develop at least 60 mW of electricity. This is to be followed by the construction within 5 years of three water-moderated reactors having power outputs of 100, 180, and 250 mW

respectively. At Harwell we are carrying out a design study of a light-water moderated reactor to assess its possible advantages over our graphite-moderated reactor.

In a reactor of this kind operating on the steam cycle shown in Fig. 5, the operating pressure will be of the order of 1,500–2,000 lb/sq. in., so that the pressure drum will be about 10 ft dia. A characteristic of a light-water moderated system is that the uranium rods are closely spaced in the lattice so that a large amount of uranium can be accommodated, and this together with the good heat-transfer properties of water means that the total heat

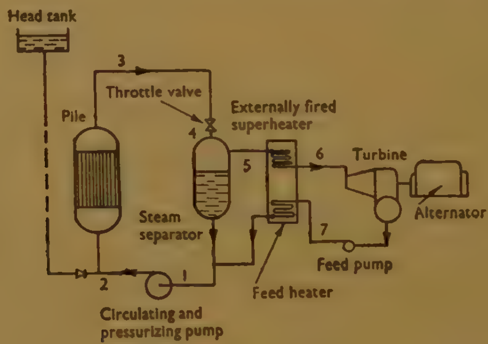


FIG. 5.—STEAM CYCLE FOR USE WITH LIGHT WATER

output can be large and an electricity output of the order of 150–250 mW from a single unit seems likely to be possible.

An alternative design of a water-moderated reactor is the so-called boiling reactor which has already been built in experimental form by the United States. The boiling reactor generates steam inside the reactor drum and the steam passes straight to the turbine, so that heat exchangers are eliminated. This enables lower pressures to be used in the reactor drum but exposes the turbine to possible radioactive contamination arising from defective fuel elements. The U.S. experiments carried out by the Argonne National Laboratory suggest that the boiling can be achieved without undue nuclear instability and without fuel burn-out caused by steam blanketing.

The most important technological problem in a water-moderated reactor is, as usual, the development of fuel elements. The sheath has to withstand the corrosive action of hot water aided by intense radiation. Stainless steel would be a suitable cladding element but absorbs neutrons strongly and unless it can be used in thin-walled tubes would be bad for fuel economy. An alternative material is an alloy of zirconium. The zirconium must be free from the hafnium with which it is usually associated. Hafnium-free zirconium is now available but is expensive. At present prices it would add at least 0·03*d* per unit to generating costs.

The uranium itself must also withstand corrosion in case a pin-hole develops in the sheath. Corrosion of unalloyed uranium would be very rapid so some alloying seems essential, even at the expense of neutron wastage.

These problems are being studied by test loops in existing research reactors and in test loops in the absence of radiation.

The fuel for a light-water reactor can be either slightly enriched uranium or a mixture of natural uranium and plutonium. The White Paper envisages fuelling stage 2 reactors with plutonium from stage 1 reactors. We believe that it would be possible to re-cycle the fuel a number of times in such a nuclear power system and thereby to extract the heat equivalent to roughly 100,000 tons of coal. In this case fuel costs would consist largely of chemical processing costs. The United States has recently forecast a capital cost of £90 per mW for a 250-mW ordinary water-moderated reactor exclusive of initial fuel charge. Generating costs should be lower with stage 2 reactors.

Alternative second-stage reactors

Many variants of the stage 2 reactor are possible and would repay study. One of these is the liquid-sodium-cooled graphite-moderated reactor. This has the advantage of permitting high-temperature operation so that higher thermodynamic efficiencies should be achievable. The United States is building a pilot reactor of this kind giving a heat output of about 20 mW from a core 7 ft dia. × 6 ft high, and are to follow this up with a power station giving 75 mW of electrical power.

Another promising type of reactor is the homogeneous reactor being studied by the Oakridge National Laboratory. Their first experimental reactor consisted of a stainless-steel sphere, 18 in. dia., containing an aqueous solution of uranyl sulphate, the uranium being enriched in U235. The chain reaction heated the liquid to 250°C and the hot liquid was circulated through a heat exchanger to develop steam at 200 lb/sq. in.

In the second mark of this reactor the core will be fuelled with U233, a third nuclear fuel produced from thorium, and the core will be surrounded by a " blanket " of thorium in which the surplus escaping neutrons will be captured to produce more U233. It is expected that in this reactor more U233 will be produced in the blanket than is consumed in the core—the system should " breed," making possible a high heat extraction per ton of thorium.

The homogeneous reactor has been shown to be completely self-stabilizing in operation, responding automatically to changes in power demand without external control being necessary. When the generator load increases the turbine generator opens the turbine throttle valves, increases the steam demand, lowering the steam pressure and temperature and reflecting itself into increased cooling of the uranium solution. This

automatically increases the reactivity of the core so compensating for the increased load. The use of liquid fuel eliminates the troublesome metallurgical problem of solid fuel elements. It also makes possible continuous removal of radioactive waste products. On the other hand it will still contain a radioactive solution and so the whole system and particularly the circulation pumps must be very leak free. The fluid will also be highly corrosive, presenting a tough development problem for the metallurgists.

Fast breeder reactors—stage 3

In reactors of stage 2 type we have envisaged extracting the heat equivalent of up to 100,000 tons of coal from one ton of uranium. In the long run, if nuclear power is to become a major power source of the world, we should like to do ten times better than this and approach the theoretical limit of 3 million tons of coal if *all* the uranium is fissioned.

The breeding principle offers a chance of realizing this. The reactor of best nuclear characteristics for this purpose is the so-called fast reactor. Such a reactor has a core of almost pure nuclear fuel—preferably plutonium. The chain reaction proceeds in the plutonium core and surplus neutrons are captured in a uranium blanket producing more plutonium. The advantage of the fast plutonium reactor is that 2·9 neutrons per fission are available and the absorption of neutrons by structural materials is greatly diminished. Thus an ideal fast reactor should give almost two new fuel atoms for every primary fuel atom burnt.

We have built a zero-energy plutonium reactor of this kind at Harwell—ZEPHYR—to study the nuclear properties of such a reactor and have obtained very encouraging results.

But, although the fast reactor is the nuclear physicist's dream it is to some extent the engineer's nightmare. For the core size is necessarily small and the heat ratings are extremely high—perhaps 100 times greater than those of the most highly rated boiler.

The fuel-element distortion problem is also more severe than in thermal reactors since for the same ratings the neutron bombardment is 100 times higher.

Heat must be extracted by liquid sodium or sodium-potassium since water would slow down the neutrons too much. The very high core ratings necessarily result in a high rate of residual heating on shut down so that cooling must be maintained under all conditions.

The Industrial Group of the A.E.A. are now designing and building an experimental fast breeder reactor which is to be erected at Dounreay. Fig. 6 is from a photograph of a model of this unit.

The contribution of nuclear power to world power

The White Paper envisages that by 1975 nuclear power will in this country be doing the work of 40 million tons of coal a year and that in the

Fig. 6.—Experimental fast breeder reactor

1970's most of our new generating capacity might be built as nuclear power units.

If we turn from the United Kingdom forecast to a long-term World forecast, I can do no better than to quote from a recent report on World Population and Resources (Woytinsky and Woytinsky, 1953).

The Authors conclude that if coal consumption increases at the present rate of 2% per annum during the next 100 years, the world would exhaust its " proven " reserves of coal before A.D. 2070 and its probable reserves about 70 years later. This is based on a World Power Conference estimate of 1948 of world coal reserves of 6,300 billion tons.

The Authors also predict that a world-wide shortage of fuel oil may develop by the year 2000. On this basis they consider that by the year 2000 nuclear energy will be required to do the work of 400 million tons of coal a year. If by this time we have achieved breeding this would require the consumption of only 400 tons of uranium or thorium a year which is a trivial quantity. I believe that nuclear power will expand at a faster rate than this.

We may think then of nuclear power developing at first slowly, becoming important in the 1970's and becoming of major importance by the end of the century.

Professor A. J. S. Pippard, in moving a vote of thanks to Sir John Cockcroft for his Lecture, said that during the past three weeks the Institution had been remarkably fortunate. A little less than three weeks previously there had been a stimulating lecture on the conservation of natural resources, and this evening there had been another equally stimulating talk as to the possible future for amplifying and perhaps replacing those natural resources.

While Sir John had been speaking, there had flashed through his mind a certain character in the Pickwick Papers, Joe the Fat Boy, whose one ambition in life was "to make your flesh creep," and it seemed that a great many physicists had inherited Joe's mantle. It had therefore been a very great delight to hear one physicist at least talking in the Institution on the peaceful applications of this new, enormous power. An address of this sort had, he thought, been given most suitably to the Institution of Civil Engineers, and he was sure it would have delighted the heart of Mr Forrest, whose memory it commemorated.

Sir John had all the qualities of a good lecturer, but he had one outstanding gift in that the listener believed himself to understand what it was all about. Professor Pippard recalled that the first tine he had ever heard atomic energy discussed was as an undergraduate when he had heard Sir Oliver Lodge lecture. He remembered that he had gone from the lecture feeling that he really understood the subject; it was only after some hours' thought that he realized how profound his ignorance was. He was quite certain that history would repeat itself on the present occasion and that he would only realize later what an enormous subject had been dealt with, and how little he had really understood.

But while listening, one particular thought—perhaps a natural one in view of his occupation—had passed through his mind. Among the many problems with which engineers and physicists were faced in the new developments there was a special one which many of those present would appreciate, viz. that of manpower. Between forty and fifty years ago many young men were fired with enthusiasm for aircraft engineering, which was just beginning to make demands on the technological skill of the country. Now, half a century later, with greatly increased demands from that industry and for the many new developments in other branches, they were suddenly faced with what would be a terrific demand for engineers physicists, chemists, and metallurgists for nuclear energy work. That brought home very forcibly to his mind a fact which everyone had realized to some extent, namely, that the shortage of engineers and scientists was a serious problem that somehow must be solved. In fact, the primary problem of the future was to find and train the men to do all the essentia

scientific and technical work. The Institution would have to play its part; he did not know what that part would be, but it would need much thought and organization.

One point touched upon in the lecture recalled a conversation that he had with Sir John about six years previously, when returning from America. He had been at a conference in Washington at which the State Engineers had been much exercised about the disposal of waste products from their nuclear fission establishments; he had mentioned this to Sir John, who had told him that there was no need for undue worry as he was sure there was an answer to the problem. Sir John had proved an excellent prophet because, if he understood him aright, a great many of those products were going to look after themselves very quickly and the rest were going to be harnessed to do something useful.

It was a very great pleasure to have the honour of moving a vote of thanks to Sir John for an extremely interesting and fascinating address.

Mr A. C. Hartley, seconding the vote of thanks, said that Sir John's acceptance of the Council's invitation to give the James Forrest Lecture had given great pleasure; there could hardly ever have been a more interesting one in the long series of James Forrest Lectures.

Sir John had given a description of an amazing achievement in the application of science to industry. He had described the team work between the physicists, the radiation chemists, and the metallurgists, and how they were putting problems to the engineering design team, and had explained how that team tackled so many of the problems.

It was a great thrill to Members of the Institution to feel that they could play a part, with their sister Institutions, the Mechanicals and the Electricals, in the development of a great new resource which could put Britain back into the lead among the industrial nations of the world.

One absolutely firm impression he had gained from the lecture was something that Sir John Cockcroft had not told them in words but which had emerged from the way in which he had delivered the lecture. They had not far to look for the source of the great leadership which had led the team to success.

The newspapers and radio gave ample testimony of the ubiquity of Sir John, and Mr Hartley was sure that the radiation of leadership which Sir John had shown tonight had been of tremendous influence in the development of British nuclear energy. It was therefore all the greater honour to

the Institution that he had taken the time to prepare the lecture and com
to deliver it.

The vote of thanks was accorded with acclamation, and the meetin
terminated.

Paper No. 6066

THE SEALING OPERATION PROJECT ON THE ZEELAND COAST †

by
August Godfried Maris

It is with great pleasure that I have accepted the President's invitation to come to London to tell you something about the Delta Plan, or as he called it in his letter " the sealing operation."

Long ago England was still connected to the continent whilst the Rhine and the Thames flowed fraternally together into the sea. The sea level rose after the last glacial age. About ten thousand years ago the sea broke the connexion between Texel and Cromer and the waves and currents in the North Sea put much sand in motion. This sand formed the dunes along the Dutch coast. This retaining wall of dunes protected the swampy areas situated behind it. The sea broke through the belt of dunes in several places. People protected themselves against the water, making mounds to live on and to shelter their cattle in case of high tides. Later small areas were gradually surrounded with dikes and in this way the polders were formed. That briefly is the historical background.

Half of the Netherlands is below high-water level and 6 million people of a population of 10 million owe the dryness of their feet to dikes and pumping plants. (Fig. 1.)

To the north of the smoother Belgian coast are deep inlets in the Netherlands, which penetrate far into the land and into which the two main rivers, Rhine and Meuse, drain. The inlets from north to south are :— The Western Scheldt, the Eastern Scheldt, the Brouwershavense Gat with Grevelingen, the Haringvliet, and the Rotterdam Waterway (the Brielse Maas was closed in 1950).

Between the Hook of Holland and Den Helder there are no indentions in the coastline.

Then considering the islands, remnants of the old dune belt which I mentioned above, the Waddensee and the Zuyderzee (closed since 1932) are inside.

This formation means that now there are 1,670 km (1,000 miles) of dikes that have to be maintained in a struggle that will never cease ; on the contrary, there is every sign that the struggle will become greater and

† From a Lecture delivered to a meeting of the Anglo-Netherlands Society at the Institution on the 10th January, 1955.

greater because the ground is sinking, at an assumed rate of severa decimetres a century.

Thinking in military terms, the Dutch people will try to shorten thei line of defence. That was done when the Zuyderzee was closed (shortene 300 km (180 miles)). It was done again when the Brielse Maas was close

Fig. 1

in 1950 (shortened 43 km (26 miles)) and when the Brakman was closed in 1952 (shortened 22 km (13 miles)) (Fig. 2).

In 1825 there were floods that inundated large areas, especially in the north of the country.

The storm of 1953 caused a similar disaster. This time it was, however, in the south-west. (See Fig. 3.)

It is clear that safety is not yet assured in several parts of our country.

Conditions in the Netherlands are also remarkable when one looks at a typical cross-section (Fig. 4), where the Prince Alexander polder (with a level of 6 m below mean sea level) and the Hollandse Yssel (with a storm-flood level of 4 m above mean sea level) clearly show the vulnerability of certain parts of our polders.

Moreover the height of the highest storm-flood levels is still increasing. Here too again and again records have been broken. (See Fig. 5.)

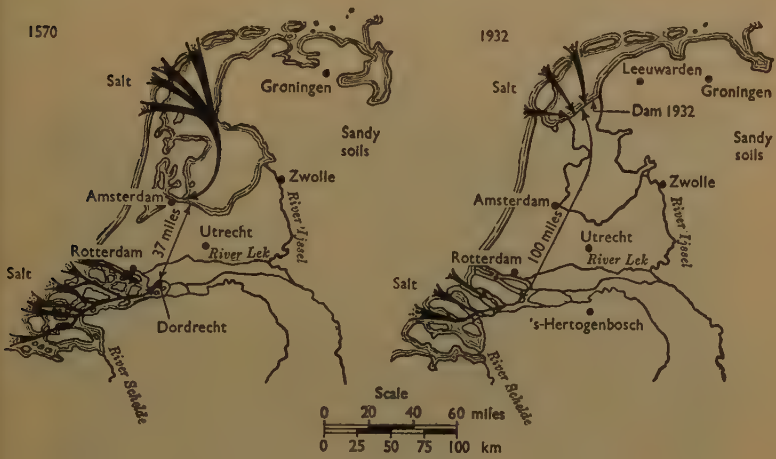


FIG. 2

This south-western area moreover suffers from drought ; at vital periods there is not sufficient fresh water for agriculture and horticulture. Finally, the region, surrounded by salt water, suffers from salinity.

Since 1937 numerous plans have been made, to shorten the coastline also in the south-west of our country. Four islands (Rozenburg, Voorne-Putten, Ysselmonde, Beyerland), or even five islands (including the island of Dordrecht) were to be brought within one ring of dykes. This would, moreover, have the advantage that within this ring fresh water could be obtained for agriculture. These plans would provide greater safety locally, but otherwise matters would remain as before.

The last scheme that was studied before the disaster of 1953 included damming up the Haringvliet and the Volkerak (Fig. 6). Both sealings are now also found in the Delta Plan. Up to that date there was no solution under consideration for Zeeland. The damming-up of the Eastern Scheldt and the Brouwershavense Gat was not included in the investigations until the Minister of Transport and Waterways had given his instructions on the 2nd December, 1952.

Then came the storm-flood of the 1st February, 1953, in which about 1,800 people were drowned, about 150,000 hectares (400,000 acres) of land were inundated, and in sixty-seven places breaches occurred.

The total damage is estimated at 1,500 to 2,000 million guilders (about 150 to 200 million pounds).

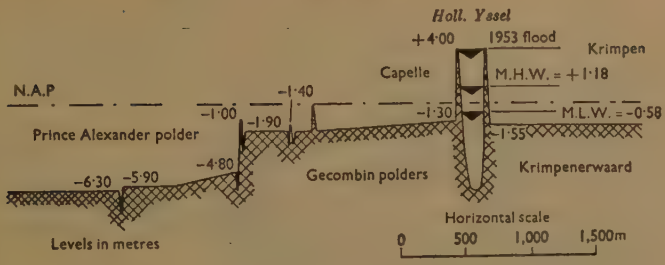


FIG. 4

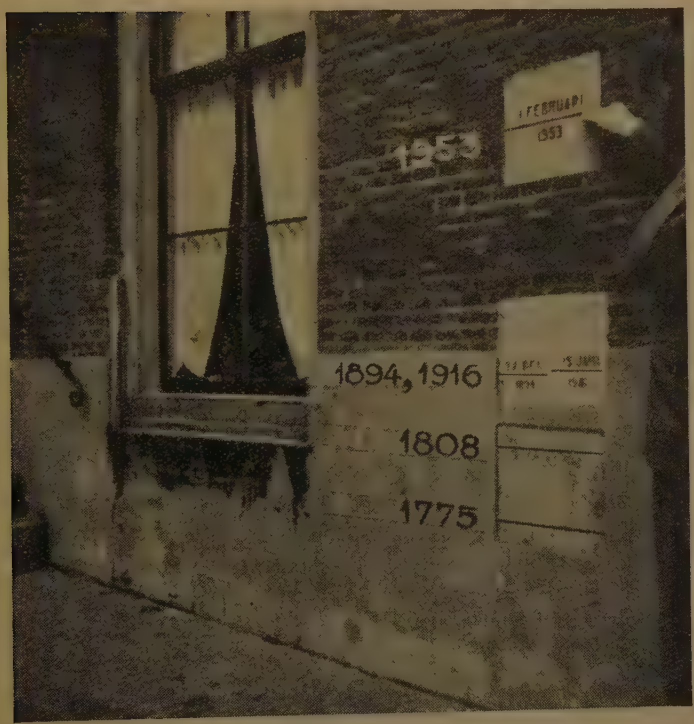


FIG. 5

A calamity of this extent had not happened for generations. One has to go as far back as 1825 to meet a comparable storm flood, that caused its greatest damage around the Zuyderzee. In 1953 the regions around the Zuyderzee were safe behind the enclosing dam, made in 1925–32. In the south hardly anybody was safe.

FIG. 6.—SCHEME WITH LARGE SLUICE NEAR HELLEVOETSLUIS

Now I want to say just a little about dike repair works.

On the afternoon of the 2nd February, we were in possession of maps made by the aid of aerial survey. Personnel were distributed over th stricken area to assist the local authorities. Materials were supplied, an 15 million sandbags were dropped from a central depot at Valkenburg Contractors with a large amount of heavy equipment were awarded con tracts to close the dikes. On Schouwen-Duiveland labour camps were no available, there was no housing for personnel, and insufficient harbou capacity for carrying out the works. The only harbour near Schouwen wa Zierikzee, crowded by vessels which were hampered very much by th currents caused by breaches of the harbour dikes. Schouwen was on sheet of water of 9,600 hectares (30,000 acres) with only a thin line separat ing the water areas, the heavily damaged dike and in the east the Schou wense dike, which only just prevented the last polders between Zierikze and Brouwershaven from being inundated. All forces were concentrate there, on the principle of keeping what you hold. At first no data abou the breaches were available, no soundings, no velocity measurements, an no heights of water levels.

It was evident, however, that more men, more equipment, and mo materials were needed. Works at the Zuyderzee were stopped, new ha bours were built, depots for materials, "zaten" (artificial beaches f making brush-wood mattresses), barracks, and whole villages followed th fleet of houseboats. The majority of all the specialists in the use of fascine (brushwood) were concentrated in the stricken area. To increase th labour force men had to be trained. The monthly production of willo

mattresses was increased to a number equal to that of a half year's work under normal circumstances. There were about 16 dredgers and suction dredgers, 55 tugs, 16 draglines, 11 floating cranes, etc., concentrated on Schelphoek.

Assistance from abroad was considerable and effective. There were 67 breaches to be closed (Fig. 7). Moreover, the dikes had sustained damage of a less serious extent in about 600 other places. In the first week

FIG. 7.—DELTA SCHEME

of February a consortium of seven contractors was awarded a contract to make and transport caissons and so-called sleeves. This consortium supplied about 700 of them. The first 100 caissons and 200 sleeves were delivered within 80 working days. They were made in Amsterdam, Rotterdam, and Keizersveer.

The requirements for the caissons were :—maximum weight 200 tons, after being filled with sand to be able to withstand water pressure from both sides alternatively (tilting and sliding).

The dimensions were $7{\cdot}5 \times 11 \times h$ (= 2, 3, 4 — 6) + max. 2×2 (sleeves) metres.

Important also were the draught while floating empty and the stability during transport, freeboard, etc.

In addition there were eight English Phoenix caissons, originally built in connexion with the invasion of France in 1944, seven of the type Ax and one Bx. Dimensions of these caissons were: Ax $63 \times 19 \times 18$ m; Bx $62 \times 13{\cdot}5 \times 12$ m.

We shall never forget the very effective and direct help of the British Army of the Rhine. They gave whatever they could. We shall always remember this neighbourly help, given at a time when you yourselves were stricken by the same storm.

Closing a breach

In closing the breach the following factors had to be considered :—

(1) Tidal difference.
(2) Size of the inundated area behind the gap.
(3) The elevation of the area in relation to mean sea level.
(4) Soil quality (resistance against erosion).
(5) Foreshore or lack of foreshore.
(6) Inner dikes.

The quantity of water flowing in and out through a gap is greater if the tidal difference is greater, the basin to be filled and emptied larger, and the area lies deeper below mean sea level.

In this respect Schouwen-Duiveland was a bad case ; moreover it had a soil which scoured easily. It had no foreshore but in the vicinity is a deep channel, the Hammen. It had no inner dikes which could have been used and heightened, to subdivide the inundated area, thus reducing the flow through the gap. The capacity of Schelphoek increased to that of the Rotterdam Waterway.

How were these gaps to be tackled ?

All along the site of the closing dike to be built we began by protecting the bottom against further erosion, by sinking brushwood mattresses weighted down with stone. These mattresses have a length, varying from 40 m beside the scoured channels, to 150 m in the deep channels to be crossed. Experience indicates that sound work of this kind will resist for some time velocities of 3 and 4 m/sec (10 to 13 ft/sec). Greater velocities become dangerous, so the system to be applied must make it reasonably sure that even at spring tides and during storms no greater velocities will occur in the most dangerous places of the cross-section.

After the floor of mattresses had been completed, it was possible to start damming up the breach. As a result the velocity increases. This confining of the profile can be effected by two methods, namely, the great length/small depth, or small length/great depth method.

The two methods are by the stone dam, or by Phoenix caissons. The stone dam, heightened with sandbags, was the old safe method of our ancestors, a system now modernized by applying, on top of the mattresses, a row of small caissons mentioned above. A stone dam was applied at Oosterland.

Closing at surface level at Schelphoek was by small caissons on willow mattresses.

With regard to the channel closing as at Kruiningen, Schelpoehk, and Ouwerkerk, the dimensions of the closing gap are determined by the maximum velocity. The dimension of the closing-gap determines the size of the caissons or caisson to be used.

These caissons can only be placed during slack water, and the time available is often short of the order of 10 min.

Now, 2 years after the storm flood, the repair work on the dikes is almost complete. This does not mean that all damage behind the dikes, too, has been repaired completely. It will still be 3 to 5 years before a normal crop can be gathered in Schouwen-Duiveland or in the polder of Kruiningen.

After this storm everybody in the Netherlands became aware that something had to be done at short notice to improve safety.

This security can be attained in four stages by :—

(1) Organizing a storm-flood warning service.
(2) Strengthening weak places in existing dike rings.
(3) The Delta Plan.
(4) The Waddenzee Plan.

The organization of the storm-flood warning service was accomplished and worked in a satisfactory way in the recent storm period before Christmas, 1954.

In the existing dike rings weak spots still remain which tend to reduce our security. If these spots are strengthened the whole defence line will become so much stronger that the risks during the period that will elapse before the completion of the Delta Plan can be accepted. The Government will contribute considerably in strengthening these weak spots.

The Delta Plan aims at securing safety, so far as is humanly possible, for the whole south-western area ; by the Plan the length of the seawall will be shortened by 700 km. (425 miles) (Fig. 7). According to the plan it is intended to close the Eastern Scheldt, the Brouwershavense Gat and the Haringvliet (see Fig. 8). Not, however, the Western Scheldt and the Rotterdam Waterway. Why not ? Theoretically it would undoubtedly be better to dam these up too. It would mean a very considerable shortening of dike exposed to storm-flood level. But Antwerp is situated on the Western Scheldt and Rotterdam on the Rotterdam Waterway. A permanent dam, naturally provided with sea-locks of sufficient capacity, would also mean a permanent series of delays to navigation. The advantages of that damming-up would have to be so considerable that very

close investigation would have to be carried out before we could think about imposing them on these great ports. It was therefore a happy

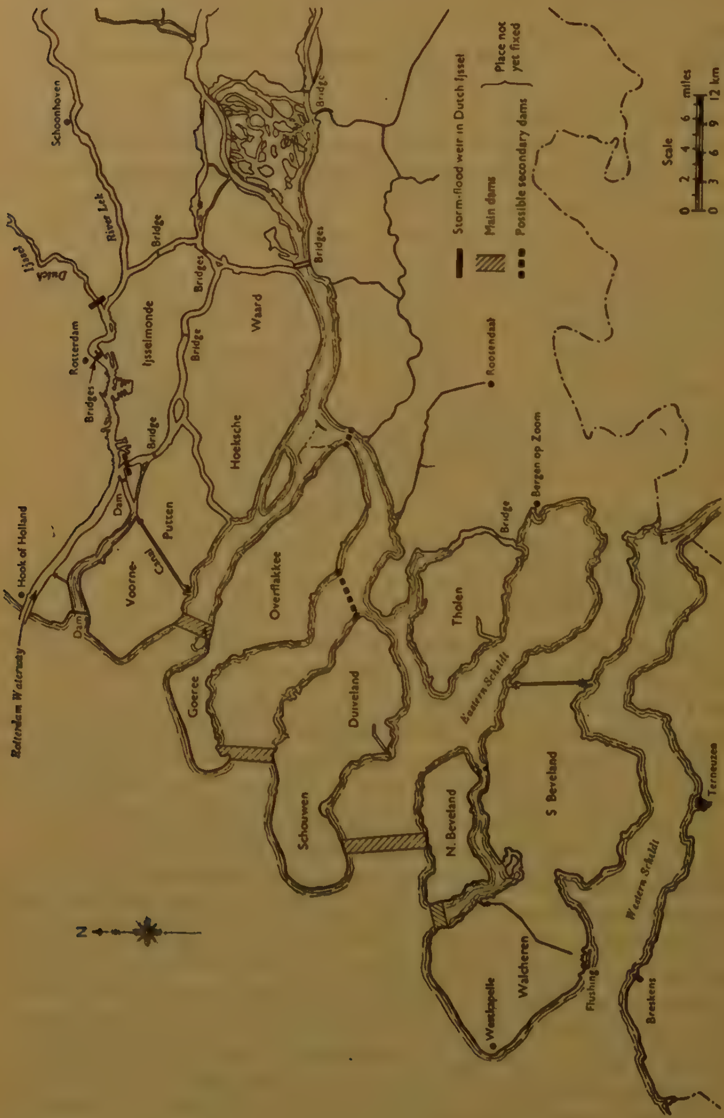


FIG. 8.—SCHEME OF CLOSING ZEELAND COAST

thought of the Minister of Transport and Waterways to confine himself to the tidal inlets situated between the Western Scheldt and Rotterdam

Waterway and to order the Delta Commission which meanwhile had been called into existence, and which can be compared to your Waverley Commission, to limit their advice to these inlets only.

All the same a small technical commission has started studying the problems connected with the building of a storm weir in the Rotterdam Waterway, capable, when closed, of keeping out storm-flood water.

The Delta Commission, installed on the 21st February, 1953, submitted its Third Interim Report on the 27th February, 1954.

Summarizing the above, the Delta Commission are of the unanimous opinion that we must enhance security in the areas devastated by the storm flood of the 1st February, 1953, and which are still in danger, by closing the tidal inlets in so far as this is not debarred under the Commission assigned to them.

The Commission consider that, from the safety angle, closing the tidal inlets is greatly to be preferred to strengthening existing dikes. They consider this solution to be economically and technically feasible.

Except for fishing and shellfish breeding, which question must be examined further, the disadvantages that may be expected owing to closure of the tidal inlets are not of very great significance, and they can mainly be obviated.

The dam will not only provide considerably more security, but will create an opportunity for ending the isolation of the island region. It will be possible, moreover, to collect a large supply of fresh water, which will help to increase agricultural production. There will also be other benefits.

The Commission therefore consider that we will have to reckon in future on closure of the tidal inlets as mentioned above, and that this project should be put into effect as soon as possible.

The Second Interim Report recommended the Hollandse Yssel to be closed by means of a stormweir with a shipping lock.

This work is in progress and it will be able to resist any storms which may occur in the winter of 1957/58.

The damming-up of the Waddenzee will be the final phase in the great plans for shortening our coastline. These Waddenzee plans are, however, in a stage hardly beyond wishful thinking.

Storm-flood level

It is difficult to decide which storm flood should be taken as a basis for the proposed works.

Formerly it was at the highest known water-level. Should this be applied now, it would be the level which occurred during the storm flood of the 1st February, 1953.

In 1937 this point of view was abandoned for the first time. It had been realized that the highest known water level need not be identical with the highest storm flood level to be expected and the experts began to analyse the factors which, together, result in this level being reached.

These factors are :—

(1) Force of the wind.
(2) Duration of the storm.
(3) The time at which the storm begins, during high spring tides or during neap tides.
(4) The course taken by the depression.
(5) The velocity with which it moves along this course.
(6) The way in which this depression changes while moving on.

For some parts of the delta areas it is moreover of importance whether the discharge of the rivers Rhine and Meuse is at high level or not.

If one considers how far these factors have been maxima in former heavy storms which have been studied, and how far the maxima of these factors can coincide and what then, in such a hypothetical case, would be the storm flood level, one would reach higher water levels than ever occurred in our rather short period of observation of 75 years. In 1940 we thought about a future level of 4 m (13 ft) above mean sea level at the mouth of the Rotterdam Waterway (the so-called superstorm), whereas the highest known level at Hook of Holland was 3·28 m above M.S.L. in 1894.

The storm of the 1st February, 1953, has shown that the highest known water level dating from before the 1st February, 1953, could be exceeded. In Zeeland it was exceeded by 60 to 70 cm (2 to $2\frac{1}{2}$ ft) and the dikes gave way over great lengths. This storm with its level of 3·85 m M.S.L. at Hook of Holland nearly came up to the theoretical super-storm of 4 m M.S.L.

The occurrence of very high storm floods may also be studied statistically. For a series of observations in a period, preferably as long as possible, the frequency of the storm-flood levels that have occurred has to be observed and by extrapolation it is possible to find which of these exceed the highest known levels.

That period of observation, however, is unfortunately very short, namely three-quarters of a century.

Although standard storm flood levels for various places along the coast have not yet been given, a water level of 1 m higher than that which occurred at Hook of Holland in 1953 and of corresponding water levels along the coast is being contemplated.

The chance of such a storm-flood level occurring in a century is about 0·01.

A purely objective rule for the standard storm-flood-level can hardly be given here.

It is, on the other hand, advisable to move away from a too strictly subjective view, by realizing that a dike of extremely high and massive dimensions, which would present only a very remote chance of being breached, might well prove to be economically unacceptable.

In considering economic aspects we can now try to come to a sufficiently objective approximation, accepting various suppositions and margins.

The line of thought in its most primitive form is as follows.

A breach causes damage to the territory lying behind to a certain number of pounds. This damage occurs on an average once in n years. If I should invest this amount in ready money in the dike and if I should, by doing so, succeed in ensuring that breaching of the strengthened dike would indeed happen so rarely that the investment would be deemed economically acceptable, then this reasoning might perhaps lead to an objective measure for the dike project.

In practice, however, this problem is not so simple.

In the first place it cannot be foreseen exactly at which water level a dike will break.

Several factors play a part; the upwash above the water level of the waves on the dike's outer slope, dependent among other things on the velocity and direction of wind, the kind of defence or revetment, and the actual state of the body of the dike during the onslaught.

Moreover it is impossible to estimate with reasonable accuracy the damage which would be caused by a future dike breach; this damage would, as time goes on, gradually become greater, as a result of new investments running parallel with growing population. And what would be the financial loss to the community?

What will be the height of the crown of the dike in relation to the standard storm-flood level after n years? In other words, to what extent should the slow century-by-century rising of the sea level, and the shrinkage of dike and subsoil be taken into account?

What might be the influence of a possible depreciation of currency, because very long periods are concerned? What is the value of human life? Of the temporal loss of harbours? Of roads?

Description of the Delta Plan

When I speak about the Delta Plan I mean the plan according to the Third Interim Advice of the Delta Commission.

We distinguish:—

(1) Three primary retaining dams, namely, in Veeregat and Eastern Scheldt, Brouwershavense Gat, and Haringvliet.

(2) Strengthening and heightening the dikes along the Western Scheldt and the Rotterdam Waterway, including the closure of the Hollandse Yssel.

(3) Secondary closures connected with the execution of primary dams (Zandkreek and Grevelingen).

(4) Secondary closures tending to improve hydraulic conditions (Volkerak and Oude Maas).

(5) Normalization works (Hollandsch Diep and Haringvliet) and additional works in connexion with drainage, navigation, and shellfish culture (oysters and mussels).

The works mentioned under (1) and (2) are necessary to ensure safety. For that reason they belong to the primary works.

To the south of the Volkerakdam the Zeeuwsche Meer will be formed; its water will ultimately become fresh, and the lake will then serve as a storage basin capable of providing water to the regions which in dry periods now suffer from salinity or drought.

The lake derives its water from the Hollandsch Diep in times of normal or great discharges of Rhine and Meuse. In these periods the quality of river water is better than in times of low discharge. The Volkerakdam makes it possible to form a freshwater basin in the south-western part of the country containing water of good quality. It is a counterpart of the Yssellake, which serves the same purpose in the north of our country.

To the north of the Volkerakdam are the waterways of the province of South Holland. They will be fed by the Meuse, the Waal, and the water of the Lek that will still be discharged through the lowest weir of the Neder-Rhine and Lek canalization.

If the supply of water from these rivers is small, the sluice in the Haringvliet will be closed. Should the Oude Maas too, be dammed up, this will mean that all the fresh water from the Meuse, Waal, and Lek will flow past Rotterdam. This will bring about an important improvement for the Rotterdam Waterway, since the salt line will be pushed farther back in the direction of the sea. Under the present circumstances 50% of the water of the Rhine, flowing to the sea by way of the Haringvliet, is lost without a similar benefit to the country.

When the discharged quantities of river water increase, the level in the South Holland waterways will rise. Should the water near the Volkerakdam rise to a level higher than that on the other side of that dam, the sluice in the Volkerakdam will be opened so as to feed the Zeeuwsche Meer with fresh water. Should the supply from upriver increase still more, there will come a moment when the sluice in the Haringvliet will be opened to discharge the surplus water into the sea. This has to be done in order to limit the velocity of the current in the river Noord. The sluice in the Haringvliet must, on the other hand, have such a capacity as to be able to handle the entire maximum discharge of the rivers Meuse and Nieuwe Merwede, reckoning with the possibility that during storms and high water in the North Sea, the discharge, which as a rule will take place at low tide, may be interrupted for some time.

There will be two basins in the Zeeuwsche Meer, the basin of Grevelingen, between the dams of Grevelingen and Brouwershavense Gat, and the basin of Veeregat and Zandkreek.

The plans for the Grevelingen basin are still being studied. Investigations are being made to determine whether it will be possible to transfer oysterbeds from the Eastern Scheldt to this basin.

The Grevelingen dam was, however, not proposed for this reason. It enables us to build the dams in the Brouwershavense Gat and in the

Eastern Scheldt, without having to execute these two major works at the same time and in tune with each other. If the Grevelingen dam is built first, the closing of the Eastern Scheldt will not cause such unacceptably strong currents in the river Zype, as would occur if the tidal river north of Schouwen-Duiveland should still be free and unhampered. The Grevelingen dam is proposed at the place where the currents from both sides round the island meet, and where subsequently the difficulties in building the dam and hydraulic consequences will be comparatively small.

Advantages and disadvantages of the Delta Plan

I shall not enter deeply into this subject since it contains various problems that are being studied by numerous experts. I should, however, like to mention certain aspects :—

(1) The important increase of safety for the inhabitants of the south-west of our country.

(2) Elimination of drying-up and salinity for an agricultural area extending far beyond the Delta regions, on account of the formation of a freshwater basin and of the receding of the salt line in the Rotterdam Waterway.

(3) Establishing better connexions for road traffic between the islands, " the Randstad Holland " and the province of North Brabant.

(4) Furthering the safety of navigation. When the Delta Plan is completed the shipping locks near Wemeldinge at the northern end of the Zuid-Beveland canal can be kept open; the shipping locks in the Volkerakdam will in fact take over the function of those at Wemeldinge.

Navigation will no longer suffer from the disadvantages of tidal differences, of the varying current velocities, and the ever-changing shoals and gullies.

The straightest possible fairways can be established and maintained at small cost.

(5) Reclamation of suitable areas (25,000 to 40,000 acres), forming a splendid recreation area for aquatic sports, which will grow more and more important since there will be no tidal movement either horizontally or vertically. Furthermore it will be within easy reach of the adjoining regions which are densely populated such as Rotterdam.

(6) Measures will have to be taken to compensate, if possible, for the disadvantages for shellfish culture resulting from the Delta Plan. Experts are hopeful with regard to lobster and mussel culture, but sceptical with regard to oysters. Possibilities are being investigated. First a thorough inquiry will have to be made concerning the factors which determine the very favourable conditions now prevailing in the oysterbeds in the

Eastern Scheldt. In addition, it will be necessary to find out what conditions of life exist in the changed situation, and not until then can an idea of the possibilities for oyster culture under the new conditions be formed.

(7) The trouble caused to navigation by ice would only be counted a disadvantage if it should be greater than it is under the present conditions. The Zeeuwsche Meer contains fresh water. If the ice along the fairway can be broken and the channel down to Wemeldinge made navigable at the same time as the canal from Hansweert to Wemeldinge is ready to be used again, there will be no disadvantage at all with regard to this important waterway. Measures should be taken to ensure that floating ice fields will have no chance of blocking up the navigation channel. To prevent this, guiding dams will have to limit and protect the fairway along certain reaches, which have still to be indicated.

It must be said that, under the present conditions after the thaw, the ice is carried off more easily towards the sea than will be the case after completion of the scheme. This also is being investigated.

So far the strengthening of the embankments along the Rotterdam Waterway and the Western Scheldt have been left out of consideration. Building them has no effect on hydraulic conditions, so construction can be carried out independently.

The Western Scheldt and the Rotterdam Waterway are comparable, but not identical. The Rotterdam Waterway will be influenced by the great storage basin to be formed between the islands of South Holland with the completion of the Delta Plan. The Rotterdam Waterway will consequently show lower storm-flood levels east of Vlaardingen than under the present conditions. The same will apply to the river Noord.

No such situation will occur in the Western Scheldt. There the water-level will not be modified by the Delta Plan. (See Fig. 9.)

Constructional methods applied in closing the gaps

The constructional method in damming up tidal inlets can in fact be the same as that in closing large breaches, namely, it should be ensured that the site for the dam, the river-bed, is able to resist scouring in case of ebb, flood, spring tides and storms, and throughout all stages of the work. Each further stage means influencing the prevailing hydraulic conditions. Each step on the work means narrowing the cross-section remaining available and consequently accelerating the velocities in certain dangerous places. At every moment it has to be known where these velocities might occur and how strong they are ; the construction should always be such that it can, at any place, resist current velocities which might occur there. That is the basis of the problem of building dams in tidal rivers.

Sand begins to move with current velocities of less than ½ m/sec. Stone derived from the coal mining industry can be used up to velocities of about 2½ m/sec. Heavy stone can resist velocities up to about 4 m/sec.

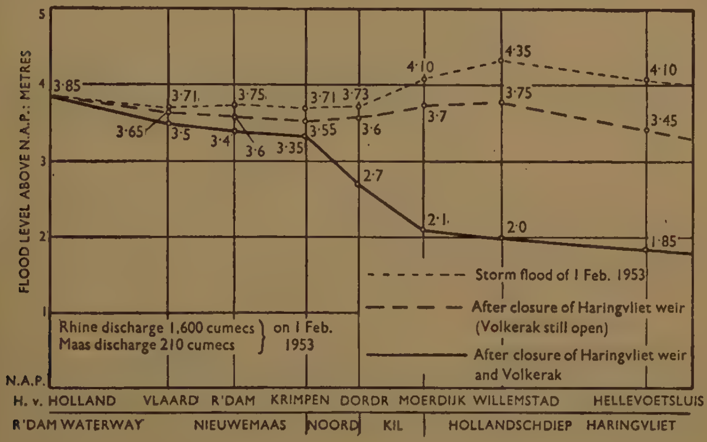


FIG. 9

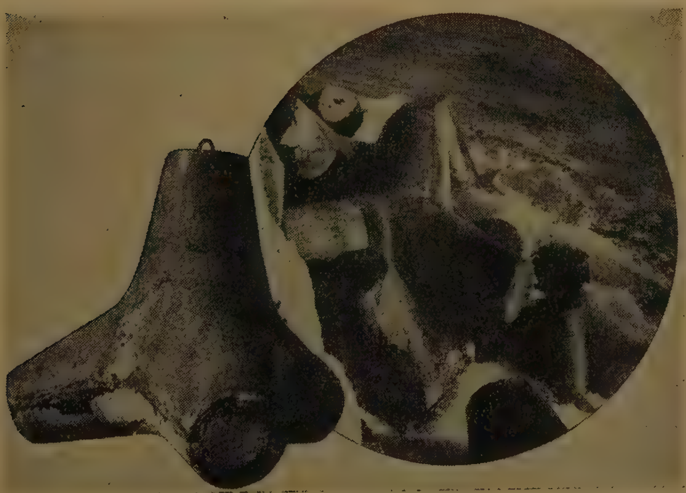


FIG. 10

If velocities of more than 4 m/sec should occur, a decision has to be taken, either to close at once and so avoid the dangerous velocities, or to use such elements that the greater velocities can be resisted. The system of

closing at once could be effected in the Brielsche Maas with one Bx caisson and at Ouwerkerk with three Ax caissons. Since, however, only one caisson of this size can be put in place during a tide, the use of ordinary caissons is limited in case the last closing gap should have to be wider. With a smaller closing gap the velocities would in such a case become too

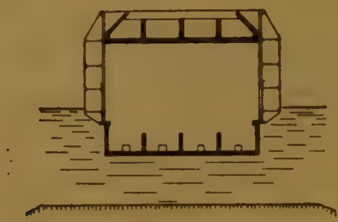
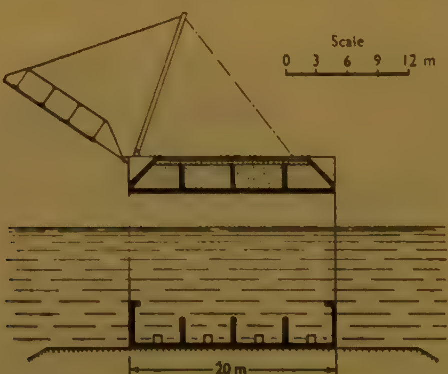


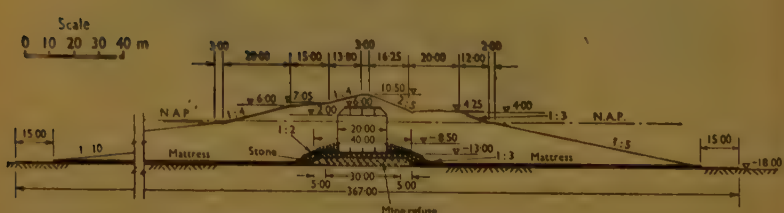
FIG. 11.—CAISSON DURING TRANSPORT

strong. Then another method may be resorted to. Two possibilities follow.

The first is that the dam through the gap is built up gradually in horizontal layers over its full length, by means of elements that can resist these greater velocities, e.g., tetraeders or tetrapods (Fig. 10).



CONCRETE CAISSON WITH OPEN VALVE



CROSS-SECTION OF THE DYKE IN A CLOSING GAP

FIG. 12

The second is closure by caissons, which at the same time can be used as sluices, being built with wide tubes which can be closed by valves on either side (Fig. 11). They are floated to the building site, with closed valves, sunk on a solid broad flat dam or sill, which is carefully prepared and consists of dumped stone (Fig. 12). After being placed the valves of the caisson are opened to enable the water to pass through as before, though slightly hemmed. As soon as the required number of caissons have been put in place, all valves are closed at slack water. After that the body of the dam of sand can be built.

Time estimate

The time needed for the realization of the whole scheme is estimated at 20 to 25 years. The northern part, including the dam in the Haringvliet and the dam in the Volkerak, can be finished in 10 years.

Cost

The cost of the Delta Plan is estimated at from 1,500 to 2,000 million guilders. If the value of the greater safety which will be brought about can be put at 500 million guilders, the whole scheme will be strictly economically justified.

CORRESPONDENCE

on two Papers published in Proceedings, Part I, January 1955

Paper No. 5989

" A Theoretical and Experimental Analysis of Sheet-Pile Walls " †

by

Peter Walter Rowe, Ph.D., A.M.I.C.E.

Correspondence

Mr G. M. Cornfield said the Author's ingenious handling of the theoretical problem had for the first time led to results which could be applied quite simply by the designer of sheet-pile walls. His experimental work described in a previous Paper [1] showed close agreement with the purely theoretical approach and lent confidence to the application of the latter to further problems.

There was one point that perhaps required some clarification. It was stated on p. 51 that the final moment reduction curve might be applied to practical cases of variable soil strata. That procedure appeared to be justified only if the soil below dredge level formed part of one uniform stratum. If there was more than one stratum below dredge level, it was not clear what value of *m* should be used.

It might be of interest to compare designs of cantilever steel sheet-pile walls based first on the graphs given on p. 40 in the Paper with those carried out by the conventional classical procedure. Three heights of wall had been examined, as shown in Fig. 28, the values of the retained heights being 7 ft, 10 ft, and 12 ft respectively. Comparative details of the resulting designs were given in Tables 3 and 4.

The soil had been assumed to be either loose ($\phi = 30°$), or dense ($\phi = 40°$), dry sand throughout and no surcharge had been allowed for. The conventional designs had been worked out for an angle of wall friction of zero, and to determine the safe penetration for those cases a factor of safety of 1·5 against overturning about point X (Fig. 28) had been used. For the designs based on the Author's curves (p. 40), the value $\alpha = 0{\cdot}5$ only had been used, as obviously $\alpha = 0{\cdot}7$ would give penetrations which would be unsafe against overturning; no indication was given in the

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† Proc. Instn Civ. Engrs, Pt I, vol. 4, p. 32 (Jan. 1955).

TABLE 3.—CONVENTIONAL DESIGN FOR CANTILEVERS: DRY SAND

Height of cantilever: ft	ϕ	δ	Bending moment: ton-in.	Section of piling	Stress: tons/sq. in.	Penetration: ft
7	30°	0°	27·1	1GB	3·5	8·8
		(20°)	(19·2)	(1GB)	(2·5)	
7	40°	0°	15·4	1GB	2·0	5·4
		(20°)	(10·1)	(1GB)	(1·3)	
10	30°	0°	74·8	1U	8·2	12·6
		(20°)	(56·7)	(1U)	(6·2)	
10	40°	0°	35·0	1U	3·8	7·7
		(20°)	(28·8)	(1U)	(3·2)	
12	30°	0°	127·0	2	8·1	15·0
		(20°)	(97·0)	(2)	(6·1)	
12	40°	0°	60·2	2	3·8	9·1
		(20°)	(49·0)	(2)	(3·1)	

NOTE.—$\phi = 30°$ was equivalent to loose sand and $\phi = 40°$ to dense sand.

TABLE 4.—ROWE'S DESIGN FOR CANTILEVERS: DRY SAND

Height of cantilever: ft	Soil	Bending moment: ton-in.	Section of piling	Stress: tons/sq. in.	α	Penetration: ft
7	Loose	19·8	1GB	2·5	0·5	7·0
7	Dense	11·1	1GB	1·4	0·5	7·0
10	Loose	55·7	1U	6·1	0·5	10·0
10	Dense	29·4	1U	3·2	0·5	10·0
12	Loose	96·2	2	6·1	0·5	12·0
12	Dense	51·7	2	3·3	0·5	12·0

Paper of a method of determining the safe penetration for a cantilever wall. Log m values of 4·75 and 6·10 had been used for loose and dense sand respectively.

The tabular results were also compared graphically (Fig. 29) and for the assumed conditions it would be noted that the conventional procedure gave moments which were consistently higher than the Author's. No direct comparison was strictly possible in view of the fact that the Author gave no indication of the determination of the safe penetration. For further comparison the conventional designs had been recalculated for $\delta = 20°$, and there the result was in extremely close agreement with the Author's values (for $\alpha = 0·5$). Conventional design on that basis would, however, give penetrations which would be too small in practice and those were not indicated in Table 3.

In the present state of knowledge regarding cantilevers it appeared that there were two possible design procedures :—

(1) The maximum bending moment for determination of the pile section could be based on the Author's method, or on the conventional method using an angle of wall friction of $\delta = 20°$. The penetration should be determined by assuming $\delta = 0°$ and allowing a suitable factor of safety against overturning.

(2) The maximum bending was determined as in (1) above, but the penetration should be calculated for $\delta = 20°$. However, the dead-weight of sheet-pile walls was insufficient to enable wall friction of that amount to be mobilized for passive pressures in the special case of cantilever walls. It therefore became necessary to increase the calculated penetration by an amount to provide sufficient uplift resistance equal to the vertical component of the passive pressure ; that was equivalent to artificially increasing the dead-weight of the piled wall.

It would be of interest to have the Author's views on that question of determining a penetration which would provide an adequate factor of safety against overturning, and to know if any experimental work had been carried out in that connexion.

The cantilever walls compared above were not cases which would often be met in practice—there would normally be changes in strata, as well as a ground-water table. The Author's curves for cantilevers as given in the Paper would, however, appear to be applicable only to the case of a uniform stratum, either dry or submerged, throughout ; additional curves to cover more practical cases would be very useful.

Dr Rowe's work, both experimental and theoretical, might enable a more accurate estimate to be made of the stress in an anchored sheet-pile wall under working conditions, but it was by no means certain that walls of different flexibilities designed in the manner suggested would all have an equal factor of safety against failure of the material of which the wall was composed. The following was a preliminary attempt to examine that question for anchored walls on the basis of the Author's moment reduction/flexibility curve.

It was proposed to compare two particular steel sheet-pile walls A and B in loose sand (the remarks which followed would, however, apply also if the soil considered was dense), but it was assumed that both walls had been designed in mild steel at a stress of just under 15 tons/sq. in. by Dr Rowe's method. Let points A and B in Fig. 30 represent the two walls, wall A being very stiff, whilst wall B was very flexible. The following symbols would be used :—

T denoted design moment by Rowe's method.
T_{max} denoted Rowe's " free earth support moment."

If the loads on wall B increased slightly due to some cause (e.g., increase in surcharge loading) the piling stress would increase, but since the design stress was just under 15 tons/sq. in. the yield stress was immediately reached and large deflexions of the wall would occur—in Fig. 30 that was equivalent to point B moving to B_1. Since B was already on the portion of the curve which was approaching the horizontal there was practically no reduction in T/T_{max} at B_1, so that only a slight increase in the loads or pressures on the wall would cause ultimate failure, assuming a stress/deflexion curve for steel in tension or compression of the form shown in Fig. 31.

If, however, wall A was now considered and again the external loads or pressure on the sheet-piling were increased, the stress again reached 15 tons/sq. in. almost immediately, yield hinges formed (as for wall B) and again $\log \rho$ increased rapidly until the wall could be regarded as very flexible. The wall could eventually be represented by point A_1 on the curve in Fig. 30—i.e., T/T_{max} had reduced from 100 to approximately 30, though the piling stress remained at 15 tons/sq. in. (the assumed yield-point value). If it was assumed that the maximum moment in the piling was proportional to the loading on the piling (in practice owing to the rise in the point of contraflexure as the flexibility of the wall increased, that was a conservative assumption) then the load factor for wall A was approximately $100/30 = 3{\cdot}3$, as opposed to about 1·0 for wall B. Therefore, though both walls were originally designed for the same stress (15 tons/sq. in.) wall A had a considerable reserve of strength, whilst wall B had none. It apparently followed that wall A was a safe design even though 15 tons/sq. in. had been used, together with Rowe's " free earth support moment "; no moment reduction was applicable to the original design since the wall was very stiff. That wall had a load factor of about 3·3, which might be considered adequate.

If wall B was also to have a load factor of 3·3 it should be designed at a stress of 15/3·3, the design moment T being $30/100 \times T_{max}$. That was, however, exactly equivalent to designing wall B for a stress of 15 tons/sq. in. but using T_{max} (Rowe's free earth support moment) as the design moment.

It was possible to generalize from the above and say that any steel sheet-pile wall would have a load factor of not less than about 3·3 if designed on Rowe's free earth support moment at a stress of 15 tons/sq. in. It would probably be more convenient, however, to use the more normal value of 8 tons/sq. in. for mild steel as the working design stress, in which case the design moment should be $8/15 \times T_{max} = 0{\cdot}53 T_{max}$.

The design would be quite independent of the flexibility, $\log \rho$, but it should be noted that the actual stress in the piling under working conditions could be obtained by using Rowe's moment reduction curve in conjunction with the value of $\log \rho$ for the piling section and length chosen. The actual piling stress might be either greater or less than 8 tons/sq. in., but the load factor would be nevertheless approximately constant.

Referring now to the contribution by Packshaw and Lake to the Correspondence [8] on "Anchored Sheet-Pile Walls," [1] in Tables 6 and 7 (pp. 627 and 628) if the factor 0·53 was applied to each of the walls mentioned for both loose and dense sands, the "design moments" (at 8 tons/sq. in.) given in Tables 5 and 6 below resulted. For comparison the conventional fixed-support moments for those walls were also given—and it should be noted that 8 tons/sq. in. would also be used with those moments in choosing a section of piling.

The reasonably close agreement between the moments X and Y did not necessarily prove that either method gave the correct answer, but it was interesting in view of the fact that the conventional method of design had been used extensively for many years and no failures, so far as was known, could be attributed primarily to the method.

TABLE 5.—LOOSE SAND ($\phi = 30°$)

Wall	Rowe's free support moment (T_{max}): in.-tons	$0·53T_{max}$ (X): in.-tons	Conventional fixed-support moment (Y): in.-tons	Difference between moments X and Y: %
A	37	20	20	0
B	200	106	102	+ 4
C	652	346	378	− 8
D	1,560	827	933	−11

TABLE 6.—DENSE SAND ($\phi = 40°$)

Wall	Rowe's free support moment (T_{max}): in.-tons	$0·53T_{max}$ (X): in.-tons	Conventional fixed-support moment (Y): in.-tons	Difference between moments X and Y: %
A	14·5	7·7	8·4	− 8
B	103	55	58	− 5
C	378*	200	236	−15
D	760	403	402	0

* The figure given on p. 628 of reference 8 was 348 in.-tons, but recalculation from the original data showed that the correct value should be 378 in.-tons.

The conclusions reached above were based on several assumptions which might not all be strictly justified, and Mr Cornfield therefore emphasized that he was not suggesting that procedure, as it stood, as a design method. It was the qualitative rather than the quantitative aspect of the results which was important. It was understood that the Author had done some

[8] P. W. Rowe, "Anchored Sheet-Pile Walls." Proc. Instn Civ. Engrs, Pt 1, vol. 1, p. 27 (Jan. 1932). *See Correspondence.* Proc. Instn. Civ. Engrs, Pt I, vol. 1, p. 616 (Sept. 1952).

work on that particular question of the true factor of safety of sheet-pile walls and it would be of great interest to know whether the tentative conclusions described tended to agree in some measure with the results of experiment on models, and to have his views on the subject.

Mr G. B. O'Rorke observed that the Author claimed on p. 51 that the percentage reduction curve might be applied to practical cases of variable soil strata, because it was independent of the value of the active pressure coefficient $K_a\gamma$. However, in spite of what was said in the Paper about the experimental study of the soil stiffness modulus m, it was not clear what design procedure should be followed in cases where m also varied from stratum to stratum.

It would be helpful if the Author would give a summary of design procedure, similar to that in Paper No. 5990,[9] for the case of the anchored sheet-pile wall.

The Author, in reply, thanked Mr Cornfield for his opening remarks and for his detailed study of the Paper. Such comparisons of research results with established practice, following those of Packshaw and Lake[8] were an essential step towards the adoption of a simple economical design procedure.

With reference to cantilever piling, the Author did not give further information regarding the safe penetration depth since that had been fully considered previously[10] when the penetration coefficient α for uniform conditions was given by:

$$\alpha = 1 - \sqrt[3]{\frac{(K\gamma)_a}{(K\gamma)_p}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$

Using $\delta = \frac{2}{3}\phi$ for Ka and $\delta = 0$ for Kp with a 1·5 factor for safe design, the values in Table 6 were obtained.

TABLE 6.—COMPARISON OF PENETRATION COEFFICIENTS

ϕ	Failure		Design equation (36)	Brinch Hansen design	Table 3
	Calculated: equation (36)	Observed			
30°	0·64	0·65	0·48		0·44
36°	0·73	0·73	0·57	0·57	
40°	0·78	0·77	0·61		0·56

The values observed at failure agreed well with equation (36) and the

[9] P. W. Rowe, "Sheet-Pile Walls Encastré at the Anchorage." Proc. Instn Civ. Engrs, Pt I, vol. 4, p. 70 (Jan. 1955).

[10] P. W. Rowe, "Cantilever Sheet-Piling in Cohesionless Soil." *Engineering*, vol. 172, p. 316 (7 Sept., 1951).

design value at $\phi = 36°$, agreed well with Brinch Hansen's method. Both methods showed a saving on the conventional procedure.

The information on the bending moments in cantilevers was intended mainly as a stepping-stone towards the solution of the anchored pile. It had been shown that the value of τ at the junction of the operating and structural curves was about 10·5 lb. in./ft⁴ units for $\gamma = 100$ lb/cu. ft and proportional to γ irrespective of ϕ. That was because the smaller ϕ, the larger α, and the larger log m. For ϕ varying between 25° and 45° the maximum error in the value of 10·5 was about 4%. The flexibility number was given by:

$$\log \rho = -0{\cdot}22 - 1{\cdot}5 \log \gamma$$

and for $\gamma = 110$ lb/cu. ft in Mr Cornfield's examples

$$I = \frac{64}{10^6} . H^4 \text{ in.}^4/\text{ft.}$$

The designs given in Table 4 were recalculated in Table 7 and showed a decrease in penetration and stress compared with the conventional procedure. No sections had been chosen, but the available sections listed in the last two columns of Table 7 indicated that the wide spacing of available sizes completely obscured the delicacy of the design method used.

TABLE 7.—AUTHOR'S DESIGN FOR CANTILEVERS—DRY SAND

ϕ	α	h: ft	$H = h/\alpha$	Bending moments: ton in./ft		I: in.⁴/ft	Available Larssen piles	
				$\frac{10{\cdot}5 \times l \,.\, l \times H^3}{2{,}240}$	Equation (18) and structural and operating curves		No.	I
30°	0·48	7	14·6	16·0	15·5	2·9	OGB	3·2
		10	20·8	46·2	47·0	11·9	1C	3·6
		12	25·0	80·4	82·0	24·8	1GB	19·9
40°	0·61	7	11·5	7·8	7·3	1·1	1U	23·2
		10	16·4	22·6	21·2	4·6	2	62·0
		12	19·7	39·2	37·2	9·6	3	122

Both Mr Cornfield and Mr O'Rorke raised the question of variable soil strata. The remarks on p. 51 referred to the fact that the initial free-earth-support diagram could be drawn for the actual strata and water pressures and that the reduction curve applied to the maximum bending moment obtained for the corresponding safe value of α. In addition, it was necessary to take varying subsoil compressibility into account.

No experiments had yet been made with variable subsoil states and

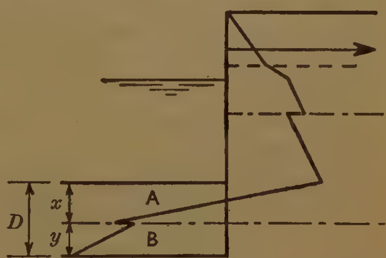
before that was undertaken it was necessary to know what were the situations most likely to be met in the field. The strata might vary along the width of the wall as well as in depth. In that case the designer might well take the worst values for design unless the site investigation was very extensive. Very wide variations in log *m* were necessary to cause significant differences in the wall stress, in view of the wide spacing of available steel sections. However, the stiffness of the stratum immediately at the dredge level was the more important. The following formula averaged the log *m* values for a two-layer system A — B, Table 8, with the upper layer value weighted twice that of the lower, and simply represented the judgement of the Author in the matter.

$$\text{Mean log } m = \frac{2\frac{x}{y}\log m_A + \log m_B}{2\frac{x}{y} + 1} \quad . \quad . \quad . \quad (37)$$

If strata A and B were very loose silt and dense sand with log *m* values 4·0 and 6·0 the mean values in Table 8 were obtained.

TABLE 8.—MEAN LOG *m* VALUES

Depth of strata A	$\frac{x}{y}$	Strata A loose silt	Strata B loose silt
$\frac{1}{3}D$	$\frac{1}{2}$	5·2	4·8
$\frac{1}{2}D$	1	4·6	5·3
$\frac{2}{3}D$	2	4·4	5·6



Clearly if A or B was very thin it should be neglected. If a strata variation in sands and silts arose which left the designer in doubt as to the adoption of the size of section, the Author would be pleased to run a model test to simulate the actual field conditions if that was possible.

Mr Cornfield's observations on the factor of safety against failure were important issues which ought to lead to economy in wall design. The original proposals by the Author simply followed normal working stress procedure. Since then, the use of the structural curve at yield had been proposed,[11] and an investigation of the flexibility characteristics of sheet walls had been made [12] in which the behaviour at yield and at ultimate failure had been studied. As a result the Author pointed out that the structural curve at *yield* should be used to design to a definite factor against

[11] Proc.W. 3rd. Int. Conf. on Soil Mechanics, Zurich, 1953, vol. III. Disc. by P. Rowe in Session 7, p. 202.

[12] P. W. Rowe "The Flexibility Characteristics of Sheet Pile Walls." *The Structural Engineer*, vol. 34, p. 150 (May 1955).

yield. That had been studied further in a Paper recently presented to the Institution.

Referring to Fig. 30, the walls A and B were both allowed to yield and the moments *subsequent* to yield were considered. However, the factor against yield starting was the important one. Also the displacement AB should equal A_1B_1, which was about 0·5 log ρ units between first yield and ultimate. Therefore B would not necessarily be at the minimum moment.

Nevertheless, for reasons different from those given by Mr Cornfield the operating and structural curves at first yield met at moments between 0·38 and 0·25 for sands, and the conclusion regarding the factor of about 3·3 on 15 tons/sq. in. designing on τ_{max} was, broadly speaking, correct. Mr Cornfield then showed that that was about the same as using the conventional method at 8 tons/sq. in., but for years that method had been used on the assumption that the factor was only 15/8. Design could now be made accurately to that factor by designing a section at 8 tons/sq. in. to withstand the limiting moment using the structural curve at yield. The working stress would then be between 11 and 12 tons/sq. in. but the factor against yield would be 15/8. The conventional procedure, known to be more conservative than the Danish method, had consistently used a factor at least 1·4 larger than that assumed. It was not surprising that no walls had failed. In that question, therefore, lay the main source of economy which could result from the research and the comparisons with conventional design.

The following was a summary of design procedure for pinned walls, as requested by Mr O'Rorke :—

(1) In addition to normal site investigations, estimate the soil stiffness moduli from penetration tests and adopt a mean value rather as indicated in equation (37).

(2) Draw the free-earth-support diagram for the variable strata and determine α, T, and M_{max}. Divide M_{max} by H^3 to give τ_{max} in in. lb/ft^4 units.

(3) Draw the moment/flexibility curve from Fig. 11 or Fig. 17.

(4) Draw the structural curve at first yield with the help of reference 9.

(5) Design the section to a chosen factor on the τ value at the intersection of the operating and structural curves.

(6) If the reinforcement of concrete walls exceeded that necessary for the driving stresses, Fig. 15 and Fig. 16 of reference 1 indicated the distribution of moment. Any particular case was calculated using the tie load (equation 30) and pressure distribution above the dredge level, and equations (11), (18), and (23) below the dredge level.

(7) For driven and dredged walls with small tie yield a load factor of 1·2 at $\beta = 0{\cdot}2$ and 1·0 for $\beta = 0{\cdot}1$ was advisable on the free-earth-support tie load. Otherwise that load should be used with no reduction for flexure.

Paper No. 5990

"Sheet-Pile Walls Encastré at the Anchorage" †

by

Peter Walter Rowe, Ph.D., A.M.I.C.E.

Correspondence

Mr G. M. Cornfield observed that the Author had extended his theory to cover the still more complex case of a sheet-pile wall fixed at the head and, again, in spite of the necessary simplifying assumptions, had succeeded in obtaining close agreement between theory and experiment as indicated by the curves in Fig. 12.

Unfortunately, as shown by the curves in Fig. 13, agreement was poor for more flexible walls due to the effect of soil arching. Since there was very little quantitative data available on arching, the design of a wall became much less precise in those circumstances. It was assumed that the experiments carried out by the Author in that case were on walls which were dredged, and not filled—and that in the case of a filled wall arching would not occur or would be much less pronounced. It would of course be safe to design on the Author's theory and neglect arching completely, but that could lead to over-design in some cases. It was probable that sheet-pile walls would be designed for fixity at the top generally in the case of high walls only, and since that resulted in high values of flexibility, arching became important.

Both the theory and experiments carried out had been based on assumptions of complete fixity in direction and of no horizontal movements at the head of the piling. Some such rotation and movement would in fact occur and, though that might be small, could have an appreciable effect on the bending-moment distribution. In general the effect would be to reduce the moment M_T and increase the moment M_C.

An example of an actual design, as shown in Fig. 16, had been worked out by the following three methods and the results were given in Table 1 (arching had been ignored) :—

(1) The method put forward by the Author. It had been assumed that the safe penetration was obtained exactly as if the wall was pinned at the top.

(2) An extension of Blum's method. A bending-moment link polygon was first drawn in the usual manner from the conventional active and passive soil pressure diagrams. The

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† Proc. Instn Civ. Engrs, Pt I, vol. 4, p. 70 (Jan. 1955).

TABLE 1

Soil	Method of design	M_T: in.-ton	M_C: in.-ton	M_D (below dredge level): in.-ton	Steel sheet-pile section	Maximum stress: ton/sq. in.	Penetration: ft
Loose sand ($\phi = 30°$)	(1) Rowe *	712	447	—	5	12·9	21
	(2) Conventional	630	407	415	5	11·4	23
	(3) Modified conventional	458	458	458	5	8·3	22
Dense sand ($\phi = 40°$)	(1) Rowe †	294	189	—	4B	6·9	12
	(2) Conventional	308	196	292	4B	7·3	14
	(3) Modified conventional	250	250	250	4B	5·9	13

* $\log mp = 2{\cdot}1, \alpha = 0{\cdot}68$.

† $\log mp = 3{\cdot}2, \alpha = 0{\cdot}79$.

assumed conditions of zero deflexion and slope at both the head and toe of the piling were then satisfied by drawing the closing line to the link polygon, by a process of trial and error, in such a position that the algebraic sum of the moments of areas of the resulting bending-moment diagram, taken about a point at the head of the piling, was zero, and was also zero when the moments were taken about the toe of the piling.

(3) Involved the drawing of a bending-moment curve exactly as in method (2) above, but in that case the closing line was drawn so that moments M_T and M_C were equal and were also equal to the maximum moment below the dredge level. The tentative assumptions on which that procedure was based were that a similar bending-moment distribution would apply in the ultimate or failure condition, and the drawing of a closing line to produce three equal moments was equivalent to the procedure adopted in the design of steel structures on the plastic theory, i.e., it was assumed that yield hinges would form at the three points of maximum bending moment. Reference to Fig. 9 indicated that as the value of log mp increased (and that was equivalent to the conditions obtaining when yield hinges had formed) the values of M_T and M_C apparently tended to become equal, for a given value of α. Figs 6 and 7 also showed that for high values of log mp the bending-moment diagram took a form not very dissimilar to that obtained by method (3); slight rotation or forward yielding of the platform would also tend to equalize M_T and M_C.

The figures, given for comparison in Table 1, showed that the results obtained by methods (1) and (2) did not differ very greatly, but method (3) did in each case give a somewhat lower design moment. The safe penetrations were almost identical for all three methods of design. Method (3) was put forward for comparison only, and further knowledge concerning the ultimate strength of those structures was required before that method or any modification of it could be applied with greater confidence to actual designs.

The Author, in reply, stated that Mr Cornfield had made some very interesting comparisons of possible methods of wall design. It was true that the built-in moment would decrease with slight rotation of the anchorage and so increase the central moment. It would be reasonable therefore to design the wall to the average of the two bending moments by any method. Furthermore, if an alternative limit design was to be proposed, it might well be compared with the Author's own method using the structural curve at yield which gave a design moment of 470 in. ton/ft for the example with loose sand. That was also in close agreement with Brinch Hansen's three-hinge procedure although his design moment was larger since it already included a factor of safety in the soil constants.

Both Brinch Hansen's method and the modified conventional method by Mr Cornfield ignored the soil compressibility. Figs 6 to 8 showed that for practical pile flexibilities the yield stress was reached first at the top, next at the centre, and last below the dredge level. Yield might occur at the top, but it did not necessarily follow that two more hinges would develop, if the subsoil was silt. However, vertical thrust as indicated in Fig. 15 (e) of reference 1, definitely prevented ultimate collapse of encastré walls in bending and that, rather than soil arching, he now believed was the cause of the difference in Fig. 13. In the result, it had not been possible to cause "ultimate collapse" of a pile with $\log \rho = -1{\cdot}3$ in loose sand. For those reasons there seemed to be no objection to economizing by using a limit procedure provided a working stress close to yield at the top of the wall was acceptable.

CORRESPONDENCE

on a Paper published in Proceedings, Part I, November 1954

Paper No. 5986

"Strain Measurements on the Temporary Road Deck for the Toronto Subway" †

by

William Robert Schriever

Correspondence

Mr E. A. Cross (Consulting Engineer, Toronto, Ontario) stated that the Paper provided some much needed information on full-scale load tests of a structure in actual service and the results were extremely valuable to all engineers designing structural steel, particularly in times when steel was in short supply. The end restraint obtained with conventional jointing was clearly shown. Knee braces were usually included only as secondary bracing members, whereas the Paper indicated that they could act as an essential part of the primary design and could, when properly proportioned, materially reduce the bending moment on the beam to which they were connected.

The advantage of a load-test safety factor had been clearly demonstrated by Mr C. M. Goodrich, Chief Engineer, Canadian Bridge Co., when in 1910 he designed hydro-electric transmission towers by applying cables to full-sized models and testing them to destruction. Very considerable savings were made compared with towers designed by conventional stress methods. The towers had proved very satisfactory in actual service.

Nevertheless, the structural steel industry in Canada had been slow to take advantage of the end continuity of members. Reinforced concrete took full advantage of such continuity and definite rulings were laid down in building codes to cover that condition. General clauses covering "rigid" and "semi-rigid" designs were included in some codes for structural steel, but their use in practice was not very general. The majority of steel structures were still designed on the basis of unrestrained end connexions for beams and columns, and for pin-connected joints in trusses. It was obvious that much more consideration should be given

† Proc. Instn Civ. Engrs, Part I, vol. 3, p. 720 (Nov. 1954).

both to the general design and the detailing of joints, if end continuity was to be considered, and there seemed to be a certain amount of apathy on the part of some designers and fabricators in that direction. That was to be deplored. Provision for end-restrained wind-moment connexions was readily covered for tall building frames and that had become standard practice for such structures. It was to be hoped that further investigations of full-scale structures under load might be made by the Division of Building Research, National Research Council, Ottawa, and that resulting from them, worthwhile savings in the steel tonnage required might be effected.

Professor G. G. Meyerhof (Head of the Department of Civil Engineering, Nova Scotia Technical College, Halifax, Canada) considered that the Paper provided a valuable addition to the scanty literature on stresses in temporary constructions where a smaller margin of safety could generally be permitted than in permanent works. It was therefore of interest to note that the maximum observed stress (9,400 lb/sq. in.) did not exceed half the maximum permissible working stress (20,000 lb/sq. in.) although under the most unfavourable combination of loads (which did not occur during the observations) the measured stresses would have been rather greater.

In connexion with the analysis of the maximum stresses in the stringers, Dr Meyerhof felt that the reason for the difference between observed and theoretical simple beam stresses was partly caused by the longitudinal distribution of the wheel loads *within* the span on account of the stiffness of the car rails, which carried part of the load and distributed the remainder through the ties practically uniformly on to the stringers. Without knowledge of the section modulus of the rails, that effect could not be fully ascertained, except that uniform load distribution gave a maximum theoretical simple beam stress of 11,000 lb/sq. in. ignoring the rail section; that stress was about 1,500 lb/sq. in. greater than observed. Since about 500 lb/sq. in. could be explained by the measured longitudinal distribution into adjacent stringers, any lateral distribution through the timber ties was small, as would be expected.

Dr Meyerhof wondered if the Author could provide a corresponding theoretical analysis of the maximum stresses in the main deck beams for comparison with the observed values. Such a comparison would provide further information on the effect of longitudinal and lateral load distribution or composite action, which was likely to be much greater for the main structural members than for the secondary members considered above.

Professor S. D. Lash (Professor of Civil Engineering, Queen's University, Kingston, Ontario) observed that the results reported by the Author were a useful addition to the rather limited amount of information available on the actual behaviour of bridge decks and similar floors in service. Studies of that kind could do much to accelerate progress. It

was clear from the observations that the maximum combination of design loads did not occur during the test period but it obviously could have occurred at any time and was therefore a proper loading to assume in design. It was equally clear that the same combination of loads could have been supported quite safely by a much lighter structure.

The Author did not state what allowable stresses were used in design, nor did he indicate what stresses were expected, but it was interesting to note that the bending stress in the deck beam at Shuter Street calculated in the usual way without allowance for end restraint or for distribution of load to neighbouring beams was approximately 11,000 lb/sq. in. That dropped to about 9,000 lb/sq. in. if an allowance was made for distribution of load to neighbouring beams by assuming the beam to be the central beam of a grid composed of three beams and two continuous stringers. That agreed reasonably closely with the maximum stress of 8,500 lb/sq. in. observed in the field. It also indicated that the deck beams were not appreciably restrained by their end connexions. It would have been interesting if the Author had measured bending moments at several sections of the beam so as to make it possible to draw bending-moment diagrams and thus verify that point.

It was regrettable that the amount of information presented on the effects of impact was so slight. The "impact factor" involved more guessing than anything else in the design process and the Subway appeared to have offered rather favourable opportunities for studying the actual effects of moving loads. Possibly the strain-measuring equipment used was not well adapted to measuring transitory strains.

The Author's observation that "impact effects decreased with increasing load" was significant and suggested that it was unreasonable to attach much importance to impact for highway loadings.

The Paper threw some light on highway loadings and their effects but, like other field tests, it gave little indication of the ultimate load capacity of the structure. If similar work was attempted on future Subway extensions in Toronto perhaps it would be found possible to test a beam to failure.

Mr Bernard Bramall (Bridge Engineer, Railway and Bridge Section, Corporation of the City of Toronto) stated that from the preliminary dissertation on statistical studies, an impression was gained that the histogram in Fig. 10 might be extrapolated to infinite strain and that, as a consequence, it would be impossible to guarantee absolute safety. Certain maxima could be postulated, though the chance of their occurring simultaneously was slight. That possibility should be countenanced insofar as the structure should not fail catastrophically under a single application of such loading. The ability of steel to withstand occasional overstress allowed of statistical treatment taking into account the frequency of stress ranges together with the life of the structure (or the steel used in it!). A characteristic of steel, therefore, was the engineer's sanction for relaxing

his specification. Mention of supposed public wishes was irrelevant. The man in the street did not want to be "let down," cared little about strength of materials, and relied implicitly on the profession.

The Author had demonstrated clearly, however, that accepting the burden of heavy loads, there was still scope for considerable economy in a structure of that kind.

Regarding the law of superposition, there was nothing exceptional in a grid system. Applicability could be negated only by exceeding limits of proportionality in the material, or by bearing surfaces riding clear of their supports and thereby failing to transmit negative reaction. In that respect, study of Table 1 was interesting. By implication it was clear that most of the runs had been made at speed, and in those cases where it had been practicable to load both tracks at once, the recorded effect was less than the sum of the effects of the separate loads. Yet, if the result for the slowly running (southbound) street-car at Wellington Street was added to the result for the crane car, the effect was within experimental agreement with that of the simultaneous loading. It would, as a matter of practical procedure, appear likely that in the two-vehicle test, one vehicle would be at rest in the position to produce its maximum static loading, and would contribute no impact. The chance of all vehicles producing their maximum impact at the same instant, and when they all occupied a critical position was remote, and that, together with the generally lower speeds prevailing which the Author mentioned, made the addition of effects not generally valid in practice.

Plate 2 provided a good illustration of the effect of the cross-ties in transmitting a greater portion of the applied load to the outer stringer than to the inner.

Mr Bramall believed that continuity effects were of trivial account in reducing the stress in stringers. A much more important factor was assistance by the rails. The rails used in that location by the Toronto Transit Commission would have had a moment of inertia of 77·7 in.^{4} when new, and the moment of inertia of the 12-in. × 8-in. × 40-lb. beam was 310 in.^{4} Neglecting continuity even of the rails, one could, therefore, expect them to bear almost 20% of the load. Thus, they accounted for most of the 25% difference between calculated and observed stresses in the beams.

The general form of the diagrams became more comprehensible on that basis. High negative moments, which continuity would engender, were lacking, and the small reverse moments might have been occasioned by relief of rail reaction. Possibly some of the curves could have been drawn a little differently in places, but there was no inference of marked continuity nor of substantial torsional resistance from the deck beams.

If continuity was suspected, a logical programme would have been directed to deploying loads to create a large deflexion of one deck beam relative to its neighbours (perhaps by the crane car on the adjacent track,

after cutting the ties in the centre), and measuring the resulting strains in a stringer.

It remained necessary to account for the low stresses observed in the deck beams, in accordance with the proposition that the stringers behaved essentially as freely supported beams. The Author had rightly contended that end conditions could not account fully for them.

Assuming a ratio of 20 : 1 between the moduli of elasticity of steel and timber, the " steel equivalent " moment of inertia of each deck timber was 86·4 in.^{4} The capacity of a deck composed of such timbers to redistribute the loading by resisting differential deflexion between main beams must be important, even assuming the joints to be staggered alternately with timbers 24 ft in length.

FIG. 12.—FORCES ACTING ON TIMBER DECK MEMBERS

Referring to Fig. 12, it would be supposed that a point in one main beam suffered a downward deflexion d, relative to corresponding points in all adjacent beams. If F was the force required to produce that deflexion in a single timber which was continuous at that point, it followed that the force required to produce similar deflexion at the end of each of the timbers meeting in the next row would be $F/4$, and that the total force for a 2-ft length of the deck beam must be :

$$1{\cdot}5F = 1{\cdot}5\,\frac{48EId}{L^3}$$

where I denoted moment of inertia of one timber ; E modulus of elasticity for timber ; and L the length of each timber.

For $d = 0{\cdot}1$ in., the total upward reaction on a 2-ft length of main beam would be 780 lb, i.e., the average reaction per ft run of the beam would be 390 lb.

Now, supposing that one beam in isolation suffered a central deflexion of 0·1 in. and that the span was 454 in. as at Wellington Street, then the deflexion at any section distant x in. from one end, would be represented very closely by :

$$d = 0{\cdot}1 \sin \frac{\pi x}{454} \text{ in.}$$

It followed that the intensity of reaction owing to deformation of the timber was :

$$\frac{390}{12} \sin \frac{\pi x}{454} \text{ lb/in.}$$

Therefore, bending moment in deck beam arising from deck reaction

$$= \frac{390}{12} \int\int \sin \frac{\pi x}{454}\, dx dx \text{ lb.-in.}$$

$$= -\frac{390 \times 454^2}{12\pi^2} \sin \frac{\pi x}{454} \text{ lb.-in. when simply supported.}$$

At centre span :

$$\sin \frac{\pi x}{454} = 1$$

and centre bending moment = — 680,000 lb.-in., which corresponded to a stress relief of 814 lb/sq. in. (the relief for 36-ft timbers and for the same deflexion = 1,420 lb/sq. in.).

The loads enumerated (short tons) would, if carried entirely by one beam, produce a bending moment represented approximately by an expression of the form :

$$\text{Constant} \times \sin \frac{\pi x}{454}$$

Using such an expression and its second integral for $EI \times$ deflexion, it was possible to equate maximum moments and maximum deflexions for a number of deck beams. It could be shown that the magnitudes of the central deflexion were about 0·3 in. in the beam straddled by the loads, 0·1 in. in the next, very small in the next, and then slightly negative. The resulting stress should then be about 8,000 lb/sq. in. (against approximately 10,000 lb/sq. in. for a simply supported deck). If deck timbers of greater length were used, then substantially more stress relief could be accredited to their distributing effect.

In the case of the truss construction, deflexions would be of a lower order and, in view of the reduced relative deflexions between adjacent frames, assistance by the timbering could hardly play so prominent a part. If, as was presumed, the 45-lb. beam formed the lower chord, the observed stresses were obviously low. It might be wondered to what extent that member acted as a strut between piles, with contingent increase in passive

earth pressure as it elongated. Gauges placed near the ends could have yielded that information.

Simultaneous recordings for a number of points would have been useful, using a number of recorders with common time impulse and synchronizing marker. It was felt, too, that more attention might have been paid to study of impact. A selection of random records might have been made using a faster travel of the record. The ripple effect of impact might then have been measured, with possibly some assessment of structural damping.

It seemed strange that gauges were not located at points of theoretical maximum stress either on the stringers or on the deck beams. Especially was that so in view of the trouble taken to find the position of maximum stress in the knee braces.

One could, of course, always visualize a need for more records to throw light on areas of obscurity, some of which became manifest only by virtue of the tests and could not have been conceived at the time of planning a programme.

Mr Schriever was to be congratulated in proving that worthwhile economies could be made in future temporary road decks, and indicating broadly the directions in which they might be achieved.

Professor A. G. Pugsley (Professor of Civil Engineering, University of Bristol) remarked that towards the end of the introductory section of the Paper, the Author had discussed the difficulty of extrapolating the high-load end of any frequency diagram expressing his load or stress statistics, and in doing so had very properly referred to the actual physical limits set by truck sizes and the like. In spite of such difficulties, however, Professor Pugsley believed that it would be of interest and perhaps of practical value to see those data plotted on some convenient basis for extrapolation. The log-log method of plotting commonly used in aeronautical work was a very simple one and might be tried in this instance; probable physical limits could be shown on the same diagram.

The Author, in reply, observed that the correspondence had drawn attention to some points of the study which should have been covered in a more complete investigation of the subject. In answer to Professor Meyerhof no theoretical analysis of the maximum stresses in the deck beams had been made.

The importance of a load-factor of safety emphasized by Mr Cross was slowly being more widely recognized. It was partly through the medium of loading tests on full-scale structures that the attention of engineers was being drawn to the frequent discrepancy between the design stresses and actual stresses and between the stress-factor of safety and load-factor of safety. Loading tests to failure, as Professor Lash mentioned, should be done to determine the ultimate load capacity and thus the load factor of safety.

Since the margin of safety normally provided for in a structure was intended to cover not only the possibility of over-loading, but also a number of other factors such as the variation in strength of the material, the possibility of faults in workmanship, and the reduction in section due to corrosion, it was indeed not possible to guarantee absolute safety, although generally the degree of safety against total collapse was very high. But it was believed that the degree to which the " unlikely " should be reckoned with was, in the last instance, a matter of public opinion—not of that of the man in the street, as Mr Bramall had correctly pointed out, but of that represented by the judgement of the profession. In other words the question of safety was ultimately not entirely a technical one but a philosophical one. The Author thanked Mr Bramall for his interesting calculation of the stress relief derived from the deck timbers.

Following the suggestion of Professor Pugsley [2] the log–log method of plotting had been used as a basis of extrapolation of the frequency distribution of traffic loads in order to obtain the probable frequency of occurrence of given stresses. (See Table 3 and Fig. 13.)

TABLE 3.—EXTRAPOLATION OF FREQUENCY DISTRIBUTION OF STRESSES RECORDED FOR 24-HOUR PERIOD

(Deck Beam at Shuter Street)

No. of occurrences of stress per day	No. of times reached or exceeded per day		Fibre stress at centre of span in lb/sq. in.	
	N	Log N	S	Log S
383	4,567	3·660	390	2·586
1,152	4,184	3·622	770	2·888
827	3,032	3·482	1,160	3·064
726	2,205	3·343	1,540	3·188
1,254	1,479	3·170	1,930	3·286
161	225	2·352	2,320	3·365
42	64	1·806	2,700	3·432
10	22	1·342	3,090	3·490
9	12	1·079	3,470	3·541
2	3	0·477	3,860	3·586
1	1	0	4,250	3·628
Max. stress likely to be reached or exceeded once				
In 1 year . . .	1/365	$\bar{3}{\cdot}438$	8,000	3·90
In 10 years . .	1/3650	$\bar{4}{\cdot}438$	10,500	4·02

[2] A. G. Pugsley, " The Correlation of Aeroplane Loadings and Accident Statistics." Aeronautical Research Council, R & M No. 2682, London, 1951.

From the straight-line portion or " tail " of the curve in Fig. 13, which of course represents a very considerable extrapolation, it would be found, for example, that a stress of 8,000 lb/sq. in. was likely to be reached or exceeded once a year, or one of 10,500 lb/sq. in. once in 10 years. The probable maximum stress, however, given by the physical limits of the

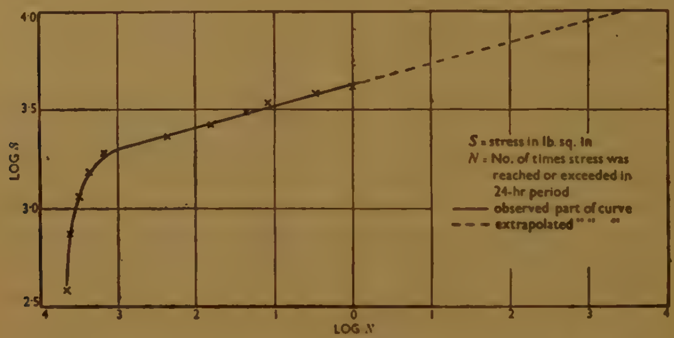

FIG. 13.—EXTRAPOLATION OF FREQUENCY CURVE OF STRESSES RECORDED FOR 24-HOUR PERIOD (BEAM AT SHUTTER STREET)

vehicles allowed, was 8,300 lb/sq. in., as obtained from the tests carried out. From the frequency curve it would appear that that stress was likely to be reached or exceeded once in approximately 1½ year. The actual frequency would probably be still lower owing to the relatively infrequent use of the crane car.

CORRESPONDENCE

on two Papers published in Proceedings, Part I, March 1955

Paper No. 6012

"The Determination of Tensile Stress/Strain Curves for Concrete" †

by

Joseph Derwent Todd, M.A., D. Phil.

Correspondence

Messrs F. A. Blakey and **F. D. Beresford** (of the Division of Building Research, Commonwealth Scientific and Industrial Research Organization, Australia) observed that the Author's work confirmed many of their own findings on the strain distribution in plain concrete beams, in particular, that microcracks developed in the beam some time before it finally collapsed. That behaviour was surprising because the classical theory of elasticity suggested that there would be stress concentrations at the apex of any such crack which would almost certainly be in excess of the strength of the material and the crack would propagate almost instantaneously.

Their work, which was fully reported elsewhere,[10, 11, 12] had been concerned with those microcracks and the conditions governing their formation, and the strain of 10×10^{-5}, quoted by the Author as having been proposed by Mr Blakey, referred to the strain at which those micro-cracks formed, not the strain (which was really fictitious since the material was no longer continuous) at final collapse of the specimen. It had been found that the load at which that cracking began might be no more than half the ultimate.

Messrs Blakey and Beresford had claimed that the tensile-stress distribution in plain concrete beams did not differ from the linear to any important degree before the cracking began. At the low strains considered it seemed unlikely that the compressive stress/strain curve could differ greatly from

† Proc. Instn Civ. Engrs, Part I, vol. 4, p. 201 (Mar. 1955).

[10] F. A. Blakey and F. D. Beresford, "Tensile Strains in Concrete. Part I." C.S.I.R.O. Division of Building Research Report C2.2–1 (1953).

[11] F. A. Blakey and F. D. Beresford, "Tensile Strains in Concrete. Part II." C.S.I.R.O. Division of Building Research Report C2.2–2 (1955).

[12] F. A. Blakey and F. D. Beresford, "Strain Distribution in Unreinforced Concrete Beams." *Civ. Eng. & Pub. Wks Rev.*, vol. 50, p. 415 (Apr. 1955).

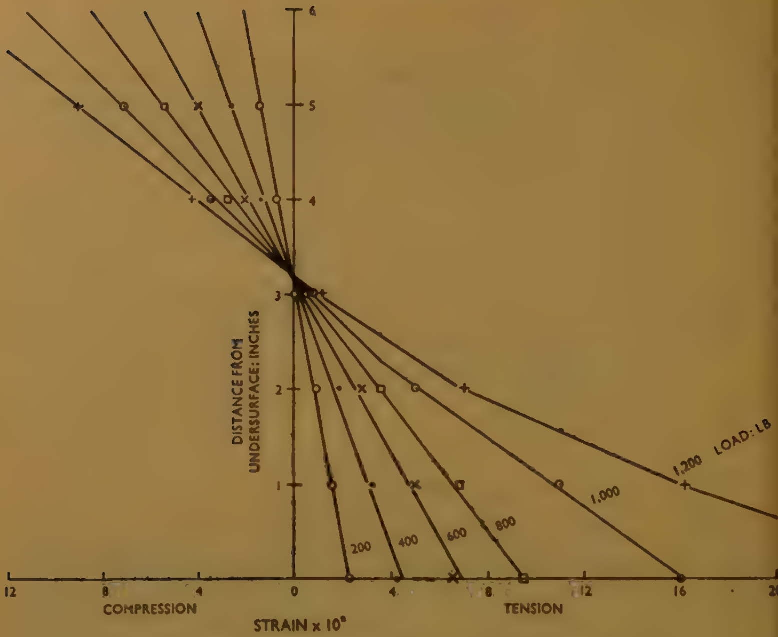

FIG. 6.—STRAIN DISTRIBUTION OVER BEAM CROSS-SECTION

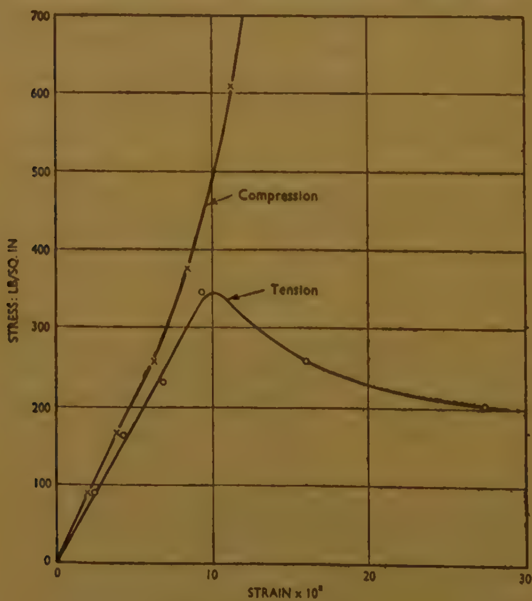

FIG. 7.—STRESS/STRAIN CURVES FROM BEAM TEST

the linear, and if so, any marked deviation from the linear of the tensile stress/strain relation would, for a given maximum stress cause the neutral axis to rise in the beam. They had not found that to happen, nor, it appeared, had the Author.

Fig. 6 showed, for different loads, the strain distribution across one of the beams tested by the writers. The distribution ceased to be linear at about 800 lb. load. From the load/strain curves from the individual gauges it appeared that microcracks started at a slightly lower load at a strain of about 7×10^{-5}. From the method given in the Paper and the strains in Fig. 6 the stress/strain curves in Fig. 7 had been obtained. From them

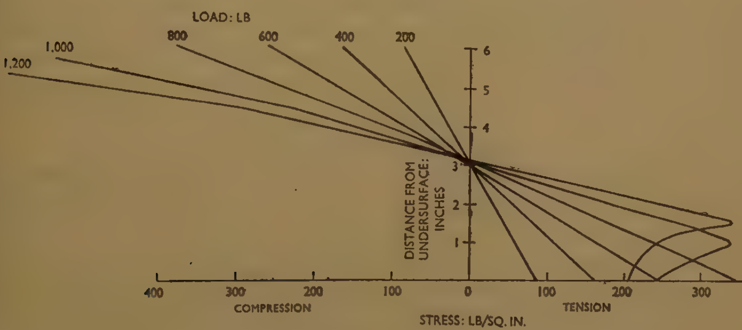

Fig. 8.—Stress distribution over beam cross-section

in turn had been obtained the stress distribution over the depth of the beam, as shown in Fig. 8. It was apparent that the stress/strain line derived in that way was virtually linear up to a strain slightly in excess of that at which microcracks developed, or about the same maximum strain in the beam at which the strain distribution over the depth departed from linear. That analysis then confirmed the claim made earlier that the tensile stress/strain relation for concrete was effectively linear until cracking began.

If that was true the interesting question remained as to the meaning of the descending part of the tension curve in Fig. 7, for that would then represent a stress in a crack. The writers believed that with the two faces of the crack in such close proximity (the width of the crack would be 1 to 5×10^{-4} in.) the free surface energy of the solid would cause force to be transmitted across the crack; such force would diminish rapidly as the crack opened wider, as the derived stress/strain curve showed.

A somewhat surprising result of the application of the analysis given in the Paper, which could be seen in Fig. 8 was that after cracking started the tensile and compressive forces, as represented by the areas under the curves, did not balance. However, after cracking started the first assumption on which the analysis was based, *viz.* that plane sections remained

plane after bending, no longer held and therefore the analysis was hardly applicable at that stage.

Mr A. C. Buck (a Senior Assistant Engineer, Messrs Binnie, Deacon, and Gourley, Consulting Engineers, London) thought that the Paper would be of particular interest to those who used the Code of Practice for the Design and Construction of Reinforced Concrete Structures for the Storage of Liquids, published by the Institution. The Code required calculations to be made for concrete sections on the assumption that the concrete sustained tensile stresses and limited the stresses to certain values : the object was to remove the risk of cracking from causes due to loading. A distinction was made between tensile stresses due to direct tension and to bending and a lower limiting figure was recommended for the first case. Thus, for direct tension, a figure of 175 lb/sq. in. was given for the tensile stress and 250 lb/sq. in. for bending. The results given in the Paper suggested that those figures might very well be made equal, although judging by the experiments it would not be wise to increase the larger stress figure.

The test specimens adopted had been very ingeniously contrived and the procedure seemed to have given more accurate results than had been hitherto achieved. The values chosen for the W/C ratios for the specimens were rather high and did not cover the range of values used in everyday works. Thus, would it not be possible to test specimens down to W/C ratios of say 0·30 ? That would increase the value of the Paper, especially since the results so far obtained gave a constant magnitude for the strain at which cracking started, which was independent of the concrete quality.

The Author, in reply, referred to the comment of Messrs Blakey and Beresford that the tensile stress/strain curve was sensibly linear and that they had observed no movement of the neutral axis. That was evident from Fig. 6, where the ratio of top to bottom strain at any particular load was a constant. The Author agreed that up to a tensile strain of about 4×10^{-5} the neutral axis remained stationary, but above that value there had been a definite movement towards the upper surface of the beam in all his tests. That was, of course, illustrated by the increasing rate of strain in the derived tensile stress/strain curves. In Fig. 6 the neutral axis was not centrally placed, indicating that the tensile and compressive stress/strain curves were different. For low strains, the Author had found that the neutral axis did in fact lie along the centre-line of the beam, making the two stress/strain curves coincident.

The derived stress/strain curves in Fig. 7 were somewhat surprising. Omitting for the moment strains in excess of 10×10^{-5}, there was a decreasing rate of strain for increasing load in the case of the compressive curve. From Fig. 6 it had been observed that the ratio of the strains at a particular load was constant. Also, the relation between the load and either of the strains was sensibly linear. Hence $M = k_1e_t = k_2e_c$, where k_1 and k_2 were different constants. It could therefore be expected that th

stress/strain relation would be linear. The Author's theory was easily modified to meet that case, whence $p_c = Ke_c$, where K was, of course, Young's Modulus.

The Author agreed that for strains in excess of about 10×10^{-5} the theory was inapplicable, for the strain distribution was no longer linear over the cross-section, which made invalid the first of the assumptions on which his theory was based.

In reply to Mr Buck, the Author would have liked to carry out tests at lower water/cement ratios, but difficulties had arisen in securing the same degree of compaction when constructing the beam and the cylindrical test pieces. That, it was felt, would be essential if comparisons were to be drawn between the two different tests. It was also thought that excessive vibration would possibly damage the waterproofed electric strain gauges.

Paper No. 6025

"Bond Stresses in Prestressed Concrete from X-Ray Photographs" †

by

Professor Rhydwyn Harding Evans, D.Sc., Ph.D., M.I.C.E.,
and
Gerald Wilson Robinson, B.Sc., Ph.D., Stud.I.C.E.

Correspondence

Mr F. J. Samuely (Consulting Engineer) observed that the problem of bond stresses was by no means solved, and any additional information at the present time was very useful. He would point out, however, that it was necessary to differentiate between two items: (*a*) the bond stresses in a pre-tensioned structural unit, and (*b*) the bond stresses in the same unit after the load was added. Further, it was not safe to draw certain conclusions, such as, for instance, that the actual bond stress near the ends of a prestressed member was equal, or even nearly equal, to the amount of bond which could actually be developed between the wire and the concrete. On the contrary, it could frequently be shown that the bond stress developed was very much smaller than the bond stress that could be taken, and that therefore a beam, for instance, could in such cases easily take additional bond stresses due to load, without any trouble occurring.

He was amazed that the summary notes, paragraph 9, p. 235, contained a recommendation. In the first instance, the subject was not treated sufficiently for recommendations to be given. Secondly, there was nothing

† Proc. Instn Civ. Engrs, Pt I, vol. 4, p. 212 (Jan. 1955).

whatsoever in the whole Paper that led up to that particular point in the summary. If it really was necessary to have all pre-tensioned beams overhanging the supports by half the transmission length (which in the case of Fig. 8 was as much as 40 in.) it would be impossible to use them in a great number of cases where they were, in fact, successfully employed. Mr Samuely had himself made a number of tests, particularly on inverted prestressed tees, with composite concrete, which produced an " I " section. He had found that bond stress had to be considered very seriously in the design, particularly, of short beams, and that the failure to consider bond might have catastrophic consequences ; but at the same time the tests had shown that a satisfactory solution could be found without any overhang whatsoever.

He pointed out that certain officials of a conservative type had attempted to use paragraph 9 of the summary in an effort to force engineers to replace prestressed concrete altogether by some more traditional construction.

Did the Authors realize the implications of the paragraph concerned ; was its inclusion intentional or an unfortunate error ?

The Authors, in reply to Mr Samuely, said it was stated quite definitely on pp. 232 and 234 that the maximum bond stress in beams cracked in flexure was considerably greater than that in a column or a pre-tensioned beam before loading. The data tabulated in Table 6 demonstrated the superiority of the general behaviour of beams over columns and reasons for that superiority were given on p. 232. The distribution of bond stress had been studied at Leeds for 12 years in both reinforced concrete and prestressed concrete columns and beams. Some of the results on prestressed concrete had already been published by Marshall [7] and Evans [8] when the experimental technique available had made it impossible to record the strains in the wires without some detrimental effect on the bond between the wires and the concrete. The results on reinforced concrete specimens had been published by Hawkes and Evans,[10] and a different method of measuring strains was adopted to determine the final distribution of bond stress.

In the Paper, X-ray photographs had been used for the determination of slip and bond stress with the object of eliminating as many sources of error as possible. The general pattern of the bond-stress diagrams obtained, no matter which of the three methods was being used, was sensibly the same and the only important difference was that the X-ray method gave higher ultimate bond-stress values. Those higher bond-stress figures were to be expected since the concrete around the wires was not now disturbed. It was therefore difficult to see how anything in the Paper could lead one to come to any other conclusions.

But it should be stressed that in both columns and beams there was a local failure of the adhesion or bond ; in the one case at the end of the

[10] J. M. Hawkes and R. H. Evans, " Bond Stresses in Reinforced Concrete Columns and Beams." *Structural Engineer*, vol. 29, p. 323 (Dec. 1951).

column and in the other at the cracks in beams. Immediately adjacent to the cracks in beams it was reasonable to assume that the maximum bond stress, as calculated in Figs 3, 10, and 11, was in fact the maximum bond stress that could be taken. That phenomenon of local bond failures was, however, an essential part of the normal behaviour of reinforced and prestressed concrete and was not to be confused with a general bond failure leading to failure of beams.

The transmission length in Fig. 8 was for smooth 0·275-in.-dia. wires and that size with a smooth surface was not usually recommended for pretensioned work. Also, as pointed out by Evans (reference 8, *see* p. 243), the important factor in calculating the required length of overhang was that the transmission length should be such that the ultimate bond stress was greater than the sum of the bond stresses induced by the pre-tensioning force and by the dead- and live-load bending moments. In other words, in an actual design the required overhang depended upon the rate of increase of the bending moment along the beam. In very long beams the results in Fig. 8 showed that an 8-in. overhang would be sufficient but that would not be so in unusually short beams with smooth 0·275-in.-dia. wires. The full transmission length, as pointed out by Mr Samuely, was 40 in. but 75% of the maximum resulting force in the wire had been transferred to the concrete in less than half of that length. The recommendation objected to in the Paper certainly provided a ready guide and, as already indicated by the Authors, the transmission length to be allowed for in the design of beams could be reduced according to the rate of increase of the bending moment near the support. Finally, it ought to be mentioned that the amount of overhang recommended for wires of 0·2-in. dia. was not in excess of that generally used in practice.

ELECTION OF ASSOCIATE MEMBERS

The Council at their meeting on the 20th September, 1955, in accordance with By-law 14, declared that the following had been duly elected as Associate Members :—

ADDLY, JAMES DENIS, B.Sc. (*Edinburgh*), Grad.I.C.E.
ANDRÉ, KENNETH VICTOR, B.Sc. (*Witwatersrand*), Grad.I.C.E.
ARMSTRONG, JOHN BRYAN, Grad.I.C.E.
BARNES, ANTHONY REGINALD, B.Sc. (Eng.) (*London*), Stud.I.C.E.
BARNES, ROY, B.Sc. (*Wales*).
BARROWCLOUGH, ALAN OGILVY, B.E. (*New Zealand*).
BARTER, HENRY GREY, B.E. (*New Zealand*).
BATHURST, JOHN, B.Sc.(Eng.) (*London*).
BEATTIE, ALEXANDER OGILVIE, B.Sc. (*Glasgow*), Grad.I.C.E.
BOX, MICHAEL HARVEY, M.Sc. (*Birmingham*).
BOYD, ROBERT REGINALD, B.A., B.A.I. (*Dublin*), Grad.I.C.E.
BRADLEY, ARTHUR GILBERT.
BRYANT, FREDERICK GLADSTONE, B.E. (*New Zealand*).
BUCKLAND, ATHOL HYLTON, B.E. (*New Zealand*).
BUCKLEY, HARRY VERNON.
BUNDRED, JOHN, M.A. (*Cantab.*), Grad. I.C.E.
BURKE, KERRAS, B.E. (*Sydney*), Grad. I.C.E.
CLARKE, MICHAEL DAVID, Grad I.C.E.
COLMAN, DAVID GERALD, Grad.I.C.E.
CULLEN, JOHN MICHAEL, Stud.I.C.E.
DAPLING, RONALD HAWKINS, Grad. I.C.E.
DAVIES, HAYDN KEITH, B.Sc.(Eng.) (*London*), Grad.I.C.E.
DAVIS, BRIAN JOHN, Grad.I.C.E.
DAVIS, FREDERICK PETER, B.Sc.Tech. (*Manchester*), Grad.I.C.E.
DAVIS, PETER BRIAN, M.A. (*Cantab.*), Grad.I.C.E.
DAWSON, DOUGLAS JAMES IMRIE, Grad. I.C.E.
DIXON, WILLIAM MAXWELL, M.A. (*Cantab.*), Grad.I.C.E.
EDMONDS, JOHN KERRIDGE, B.A. (*Oxon*), Grad.I.C.E.
FAULDS, JAMES RODGER, B.Sc. (*Glasgow*), Stud.I.C.E.
FINN, EDWARD VIVIAN.
GAFFNEY, JAMES ANTHONY, B.Sc.(Eng.) (*London*), Grad.I.C.E.
GALLIE, WALTER JAMES LOUDON, B.Sc. (*Glasgow*), Grad.I.C.E.
GARDNER, ROGER WHITESIDE, B.Sc. (Eng.) (*London*), Grad.I.C.E.
GASKELL, WILLIAM, B.A. (*Cantab.*), Grad.I.C.E.
GAUNTLETT, NOEL REEVES.
GREEN, ROBERT WIGRAM, B.Sc. (*Cape Town*).
GRESSWELL, PETER JOHN, B.A. (*Oxon.*), Grad.I.C.E.
HALL, BERNARD, B.Sc. (*Nottingham*), Grad.I.C.E.
HALL, IAN LINDSAY, Stud.I.C.E.
HARPER, GEOFFREY GARTH SHORTLAND, Grad.I.C.E.
HAWES, LEONARD DENNIS, B.Sc.(Eng.) (*London*), Grad.I.C.E.
HEDDERWICK, JAMES THOMAS, B.Sc. (Eng.) (*London*), Grad.I.C.E.
HEYMAN, JACQUES, M.A., Ph.D. (*Cantab.*).
HIBBERT, HARRY, B.Sc.Tech. (*Manchester*), Grad.I.C.E.
HOLLAND, RONALD WILBER, M.A. (*Cantab.*), Grad.I.C.E.
HOWDEN, IVOR, B.Sc.(Eng.) (*London*), Grad.I.C.E.
HUME, ERIC WILLIAM, Grad.I.C.E.
HUTCHISON, WILLIAM YOUNGSON.
HUGHES, FRANCIS, Grad.I.C.E.
JENNINGS, DONALD SUTCLIFFE, B.Sc. (Eng.) (*London*), Grad.I.C.E.
JOHN, GRAHAM LLEWELLYN, B.Sc. (*Wales*), Grad.I.C.E.
JUDELSOHN, GEORGE LEONARD, B.Sc. (*Cape Town*).
KEENE, REGINALD CAMERON.
KERSHAW, PETER JOHN, B.Sc.(Eng.) (*London*), Grad.I.C.E.
KERSHAW, WILLIAM HERBERT, M.A. (*Cantab.*), Grad.I.C.E.
KNEEN, GILBERT WILSON, Grad.I.C.E.
LE PIVERT, JOHN ALFRED, B.Sc. (*Aberdeen*), Grad.I.C.E.
LEWIS, THOMAS JAMES COLIN, B.Sc. (*Birmingham*), Grad.I.C.E.
LISTER, KENNETH FRANCIS.
LITTLEY, FREDERICK BRYAN, B.Sc. (*Birmingham*), Grad.I.C.E.
LOGIE, KENNETH FORSYTHE.

Longbottom, Derek Patterson, B.Sc. (*Durham*), Grad.I.C.E.
Lord, John Edwin David, B.Eng. (*Sheffield*).
Malone, Stephen Augustine, B.E. (*National*).
McCallum, Alexander Boyd, B.Sc. (*Edinburgh*), Grad.I.C.E.
McDowell, Charles William Michael, B.Sc.(Eng.) (*London*), Grad.I.C.E.
McLay, Alastair John, B.Sc. (*St Andrews*), Grad.I.C.E.
McMurray, Samuel James, B.Sc. (*Belfast*), Grad.I.C.E.
Marley, Paul Couch, Grad.I.C.E.
May, John Edwin, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Moore, Joseph Thompson, Grad.I.C.E.
Norris, Robert James, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Murdoch, John Donn, Stud.I.C.E.
Neville, Thomas, Stud.I.C.E.
Nisbett, David John, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Onions, Allan, Grad.I.C.E.
Pollin, John, Grad.I.C.E.
Pool, James Fraser, B.Sc. (*Witwatersrand*), Grad.I.C.E.
Powell, Thomas Gerald Michael Glyn, B.Sc.(Eng.) (*London*), Grad. I.C.E.
Robertson, Robert Forbes, Stud. I.C.E.
Rothwell, Clifford Harrison, Grad. I.C.E.
Sharp, Robert Graham, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Sheppard, Frederick James, B.E. (*New Zealand*).
Silgardo, Mervyn Bernard, B.Sc. Tech. (*Manchester*), Grad.I.C.E.
Small, Ian, B.Sc. (*Glasgow*), Stud.I.C.E.
Smallfield, Thomas Walton.
Smith, Albert William.
Smith, Desmond Evelyn, B.Sc. (*St Andrews*), Grad.I.C.E.
Smith, Sydney Maxwell John, Grad. I.C.E.
Stewart, Peter Francis James, B.Sc. (Eng.) (*London*), Grad.I.C.E.
Swan, Christopher Hugh, B.Sc.(Eng.) (*London*).
Sweetman, Murray Mayell, Stud. I.C.E.
Tait, John Bruce, B.E. (*New Zealand*).
Tapp, William Pelton, B.E. (*Adelaide*).
Taylor, Harry, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Toner, William Anthony, M.Sc. *Belfast*), Grad.I.C.E.
Tork, Andres, B.E. (*New Zealand*), Grad.I.C.E.
Tucker, Geoffrey Peter, Grad.I.C.E.
Twelves, Ivar Leslie, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Wade, Thomas Barry, B.Eng. (*Sheffield*), Grad.I.C.E.
Walker, Robert Cope, B.Eng. (*Sheffield*), Grad.I.C.E.
Webster, Kenneth Campbell, Grad. I.C.E.
Williamson, John Herbert Keppie, B.Sc. (*Edinburgh*).

DEATHS

It is with deep regret that intimation of the deaths of the following has been received.

Members

CHARLES ANTONY ABLETT, O.B.E., B.Sc.(Eng.) (E. 1907, T. 1919).
Sir ATHOL LANCELOT ANDERSON, K.C.B. (E. 1900, T. 1913) (former Member of Council).
THOMAS MORTON GOURLAY (E. 1919, T. 1943).
SYDNEY THOMAS EDWARD HEATON-ELLIS (E. 1893, T. 1908).
GUSTAVE PAUL ROBERT MAGNEL (E. 1950).
FREDERICK GASTON PENNY (E. 1915, T. 1942).
EUSTACE WILLIAM PORTER, M.B.E. (E. 1899, T. 1922).
JAMES LEISHMAN ROY (E. 1918, G. 1944).
THOMAS HENDERSON SCOTT, O.B.E. (E. 1915, T. 1924).
Major-General Sir CLIVE SELWYN STEELE, K.B.E., D.S.O., M.C., V.D., B.C.E. (E. 1918, T. 1927) (Member of Council).
ARTHUR AYTON SYMINGTON, B.Sc.(Eng.) (E. 1928, T. 1941).
ERNEST WORRALL (E. 1921).
HARRY EDWARD YERBURY, M.B.E. (E. 1909).

Associate Members

JOHN PHILIP BETT (E. 1933).
RUPERT NELSON DEARHAM (E. 1945).
LEONARD JULIUS ELGIN (E. 1945).
WILFRID HARRY GAMBLE (E. 1930).
CHARLES DOUGLAS GEE (E. 1907).
CHARLES LEAVERS HALL, B.Sc. (Eng.) (E. 1918).
PETER BRYAN HARDING, B.Sc. (E. 1946).
LEONARD THOMAS HORTON, B.Eng. (E. 1934).
HERBERT MALCOLM JORDAN (E. 1919).
ANDREW HOWIE MCBRIDE, B.Sc. (E. 1928).
HOWARD MARTINEAU (E. 1890).
SIDNEY THOMAS MONTÉ (E. 1931).
RICHARD DOUGLAS MORRIS, B.Sc.(Eng.) (E. 1914).
CHARLES FRANKLIN MURPHY (E. 1902).
EDWARD AMBROSE OLIVER (E. 1934).
SYDNEY ELLIOTT PAGE (E. 1894).
EWART RENTON SHACKLETON (E. 1942).

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